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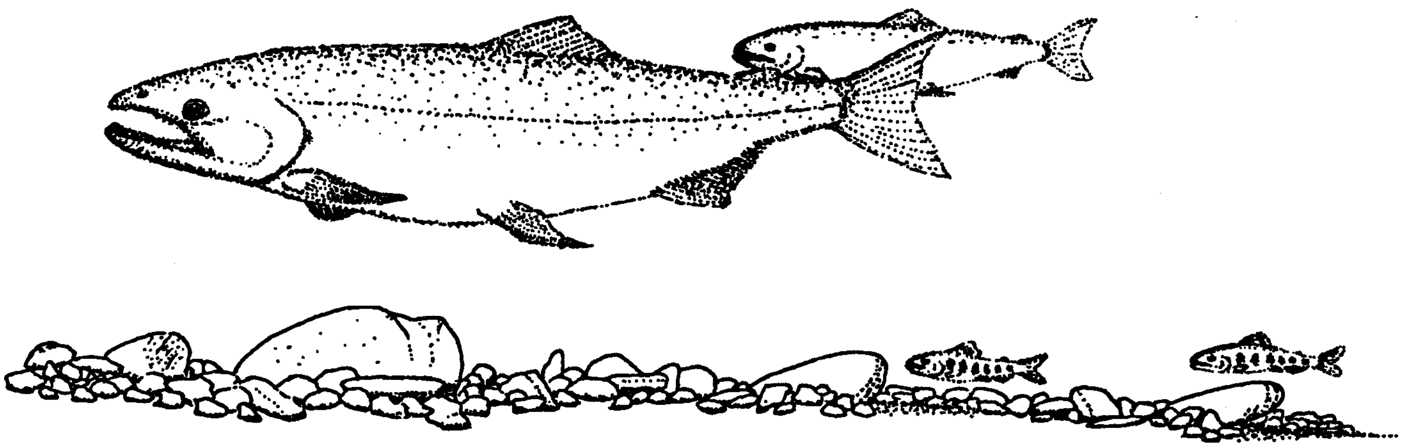
TRAVEL TIME OF COHO SALMON AND STEELHEAD SMOLTS EMIGRATING THROUGH HOWARD HANSON RESERVOIR, KING COUNTY, WASHINGTON



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Travel Time of Coho Salmon and Steelhead Smolts Emigrating through Howard Hanson Reservoir, King County, Washington

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ABSTRACT

We radio tagged, with gastric implants, 110 coho salmon *(Oncorhynchus kisutch)* and 106 steelhead *(O. mykiss)* smolts to 1) assess whether Howard Hanson Reservoir pool size affects smolt emigration and, 2) predict the effect of the proposed additional reservoir storage on smolt travel time. Each spring, the reservoir is refilled for low flow augmentation and increases from 1.3 miles (thalweg measure) to 4.1 miles in length, which may delay emigrating smolts. Under the proposed additional reservoir storage condition, the reservoir would increase to 5.2 miles in total length (thalweg measure) at full pool.

Radio-tagged coho salmon and steelhead smolts were released upstream of the reservoir at existing low, mid, and full pools and their movement was tracked with fixed and mobile receivers to the dam's forebay. Over the refill cycle, both species exhibited similar patterns in travel time, but their rates of travel differed at mid and full pools. Mean travel time of coho salmon to the forebay at mid pool (11.0 days) was significantly greater ($P < 0.001$) than their mean travel time at low pool (3.1 d) or full pool (6.0 d). Likewise, mean travel time of steelhead to the forebay at mid pool (7.4 d) was significantly greater ($P < 0.001$) than their mean travel time at low pool (2.9 d) or full pool (2.7 d). However, mean travel time of coho salmon was significantly greater than steelhead at mid pool ($P = 0.004$) and full pool ($P < 0.001$), but not significantly different at low pool.

A general linear model (GLM) analysis indicated that available environmental, physiological, and morphological variables were insufficient for predicting smolt travel times. The best model contained pool refill rate and fish weight, and had an R^2 value of 0.47. Using release group (low, mid, and full pool) as a class variable yielded models with R^2 values between 0.83 and 0.84. GLM models suggested an inverse relationship between inflow and travel time for both species when the model contained release group as a class variable. We do not, however, have confidence in the GLM model's ability to predict smolt travel time at the proposed additional storage pool level. The use of GLM was not considered in the design of this study and no variables pertaining to pool size sufficiently explained the variability in travel time. A follow-up study may be necessary to properly assess effects of pool size on smolt emigration through Howard Hanson Reservoir.

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INTRODUCTION

At Howard Hanson Dam and Reservoir on the Green River, Washington (Figure 1), the U.S. Army Corps of Engineers (USACE) and Tacoma Public Utilities (TPU) have initiated feasibility studies of Tacoma's proposal to increase useable storage in the reservoir for municipal water supply and downstream flow augmentation.

Under current conditions, Howard Hanson Dam impounds water each spring as the reservoir is raised to its full-pool elevation of 1,141 ft (above sea level). The pool may also be briefly (one to two weeks) surcharged to elevation 1,146 ft for debris removal and other purposes. Between low (1,070 ft) and full pools, the length of the reservoir increases from 1.3 miles (thalweg measure) to 4.1 miles. The reservoir is gradually drafted through the summer and fall to augment downstream flows. The proposed added storage project would elevate the spring and summer reservoir pool to a maximum of 1,177 ft above sea level, or 36 ft above the existing full-pool level of 1,141 ft, and increase its maximum thalweg length to 5.2 miles. The minimum flood-control pool elevation during winter would remain at approximately 1,070 ft. To achieve added summer storage, the start date for reservoir refill would occur sooner and the maximum size of the reservoir would be greater than at present.

The Muckleshoot Indian Tribe (MIT), Washington Department of Fish and Wildlife (WDFW), and Trout Unlimited have released juvenile hatchery coho *(Oncorhynchus kisutch)*, chinook salmon (*O. tshawytscha*) and steelhead *(O. mykiss)* in the watershed (starting with steelhead in 1982) above Howard Hanson Reservoir. Because the exits of Howard Hanson Dam were not designed to provide surface spill, emigrating juvenile salmonids are often delayed beyond their "biological window" or are entrapped at elevated reservoir levels (Dilley and Wunderlich, 1992 and 1993). Besides exit-related delay and entrapment, there is a concern that juvenile salmon and steelhead could require additional travel time while migrating through the reservoir, and thus suffer additional mortality or an increase in residualization under existing and proposed increases in reservoir storage.

To assess whether reservoir-induced delay is a concern for emigrating salmon and steelhead at the Howard Hanson Reservoir, the USACE and TPU funded a cooperative study with MIT and the Western Washington Fishery Resource Office (WWFRO) of the U.S. Fish and Wildlife Service (USFWS). This study's purpose was to assess juvenile coho salmon and steelhead passage rates through the Howard Hanson Reservoir over a range of conditions (reservoir elevations) typical of the spring emigration period. Study results were intended to characterize fish passage through the reservoir with the existing project and, if possible, assess smolt passage with the added storage project.

This report describes the tasks assigned to WWFRO in this cooperative study of fish passage through Howard Hanson Reservoir. WWFRO's tasks were to:

- Assist with field activities, data reduction, and data interpretation.
- Determine travel time of coho salmon and steelhead smolts to fixed points in the reservoir at a range of reservoir pool conditions using contractor-supplied data.
- Characterize the relationship between the observed travel times of coho salmon and steelhead smolts and the associated reservoir conditions during the period of reservoir passage.

METHODS

We employed radio tracking to monitor movement and travel time of coho salmon and steelhead smolts through Howard Hanson Reservoir during the spring/early summer refill period of 1995. Smolt release was timed to coincide as nearly as practical with the natural emigration timing of each species, and to coincide with the spring refill cycle of Howard Hanson Reservoir such that smolts encountered the full range of reservoir conditions (i.e., low- to full-pool levels and the associated changes in reservoir surface area, outflow, shoreline length, water velocity, etc.) that could affect smolt movement and travel time.

Radio tagging, fish release, radio tracking, and data reduction were cooperative efforts among the aforementioned parties. Here, we describe the major field activities and methods employed and note where WWFRO was primarily involved. However, we refer to other cooperators for detailed accounts of their activities.

Per the overall study design, radio-tagged coho salmon and steelhead smolts were released and monitored at successively higher reservoir levels over the entire refill cycle. These reservoir levels were broadly designated as low, mid, and full pools and represented the relative size of the reservoir through refill. Due to lower-than-expected runoff in the Green River during the spring of 1995, the refill cycle was accelerated and actual reservoir test elevations varied from pre-study target release elevations as follows:

Reservoir test level	Pre-study target release and fish monitoring range (ft)	Actual release and fish monitoring range (ft)
Low pool	1,070-1,085	1,077-1,103
Mid pool	1,105-1,120	1,105-1,136
Full pool	1,141-1,146	1,137-1,142

This strategy for fish release was intended to characterize typical fish passage conditions during spring refill. We hypothesized that as reservoir size increased, travel time through the reservoir would increase, thereby allowing possible development of a predictive model of smolt travel time under the added storage condition.

The coho salmon used in this study were Soos Creek stock (BY 1993) reared at Soos Creek Hatchery (WDFW), transferred to Crisp Creek Rearing Pond (MIT & WDFW) in August 1994, and finally to Keta Creek Hatchery (MIT) on April 6, 1995, where they were radio tagged. Only coho salmon greater than 130 mm fork length were radio tagged due to tag-size limitations.

The steelhead used in this study were Green River stock (BY 1993) raised at Puyallup Hatchery (WDFW), transferred to Flaming Geyser Rearing Ponds (WDFW) on April 5, 1995, and then moved to Keta Creek Hatchery on April 6, 1995, where they were radio tagged. Only steelhead smolts greater than 170 mm fork length were radio tagged due to tag-size limitations.

Fixed Receivers

We placed fixed antenna receivers with data loggers (Lotek model SRX 400, W-18[1]) at sites M, W, and Z (Figure 1). Lotek Engineering, Inc. (under USACE contract) designed and assisted with the installation of the fixed-antenna receiver system. Site M was located at mid reservoir in a narrow gorge situated 2.4 river miles (thalweg length) from site A (the release site) and 2.2 river miles upstream of the dam. Site W, in the dam's forebay and within its flow net (and the furthest downstream monitoring point in the reservoir) was 4.5 river miles below site A and 0.1 river miles upstream of the dam's intake tower. Site W was termed the "finish line" because fish detected at this point were assumed to have successfully traversed the reservoir. Site Z was located approximately 0.1 miles downstream of the dam, and served as a check for smolts passing both the reservoir and the dam.

The receivers at sites M and Z were powered by deep-cycle, 12-volt batteries that were changed twice per week, while site W's receiver was powered by 110-volt project current at the dam.

At the start of the study, each receiver system included a single, six-element yagi antenna. Beginning with the mid-pool release, however, site W was changed to a master- and auxiliary-antenna system. This change at site W substantially narrowed the detection range, which was initially too broad during the low-pool test to accurately define when fish reached the forebay. That is, fish in the low-pool release may have been detected up to 0.5 river miles upstream of site W, or approximately one-half the distance (line of sight) to site M (Figure 1); therefore travel times to site W could have been artificially shortened. After the change, fish released at mid and full pools could be detected only about 0.1 miles upstream of site W, which was the immediate vicinity of the forebay.

Calibration tests at site W confirmed that signal strength was dependent on receiver antenna orientation, receiver gain setting, transmitter antenna orientation, transmitter type (Lotek had greater range than ATS), and transmitter depth; we could control only receiver variables. As expected, the signal strength at site W decreased with transmitter depth (maximum effective transmitter depth was 10 m) and with distance (maximum effective transmitter distance was 0.5 miles at low pool, and 0.1 miles at mid- and full-pools, respectively).

Mobile Tracking

Mobile radio tracking occurred periodically at a variety of sites in the reservoir (as indicated by the small letters in Figure 1) over the study period. Mobile tracking was intended to provide information on the migration route of smolts through the reservoir, and help locate missing tags. During the first half of the study, when most tracking was done from land, we used a Telonics model TR-2 receiver with a three-element yagi antenna. During the second half of the study, when most tracking was done by boat, we used an ATS receiver model R-4000 with a four-element yagi antenna. Mobile tracking was a cooperative effort among all participating agencies (USACE, MIT, TPU, and USFWS), but MIT was responsible for compilation and reduction of the data collected.

Radio Transmitters

We used different radio transmitters for coho salmon and steelhead smolts. ATS model 379 transmitters were used for coho salmon and had the following characteristics: 1.1-1.3 g air weight; 0.8 g weight in water; 15 mm length;

[1]Mention of trade names does not imply endorsement by the USFWS.

5-6 mm diameter; 320 mm antenna; 33-35 pulses per minute (ppm); frequencies in the 150 MHZ band; and a battery life of 20 days (d).

Lotek model SFM-2 transmitters were used for steelhead tagging and had the following characteristics: 2.3 g air weight; 1.1 g weight in water; 20 mm length; 10 mm diameter; 300 mm antenna; rates of 41, 49, and 61 ppm; frequencies in the 148 MHZ band; and a battery life ranging from 26 d for 61 ppm transmitters to 37 d for 41 ppm transmitters.

The radio transmitter was implanted in the fish's stomach using a plastic pipette as a plunger. The pipette acted to enclose and protect the antenna during tag insertion (N. Adams, National Biological Service, Cook, Washington, personal communication). The transmitter's antenna was then crimped so it trailed posteriorly from the fish's mouth.

During the initial tagging of coho smolts, we found tag regurgitation to be a problem. To prevent tag regurgitation by coho smolts, a small piece of sponge was tied to the tag prior to insertion (Moser et al. 1991). Steelhead were tagged without the sponge.

All tagged fish used in the study were held for 24 hr before actual release to check for tag regurgitation and allow for buoyancy compensation. Two extra fish were tagged in each release group and used, if needed, to replace fish that regurgitated their tags.

Migratory Tendency of Smolts

Migratory disposition of smolts was assessed by measuring ATPase units (μmoles ATP hydrolyzed per mg protein per hr) (Zaugg 1982a). During tagging, five additional fish from the release group population were sacrificed for ATPase analysis (for a total of 15 fish of each species per test condition). Fish were bled by partially severing the caudal peduncle, placed on ice, and transported within 2 hr to the Olympia Fish Health Center (USFWS). There, weight and fork length were measured, and gill filaments were taken from six gill arches (three on each side). Gill tissue from each fish was individually placed in a 2-ml micro centrifuge tube, immersed in SEI solution (a preservative), and stored in a super-cool freezer (-70° C) until shipment on dry ice to Wally Zaugg (under USACE contract) at Cook, Washington, for ATPase measure.

The pre-study ATPase criteria for smolt readiness were 12-30 units for coho salmon (Schroder and Fresh 1992) and above 10 units for steelhead (Chrisp and Bjornn 1978).

Lengths and weights of radio-tagged and ATPase-sampled fish were compared using analysis of variance (ANOVA) to determine representativeness of ATPase sampling.

Release Procedure

At each test pool condition (low, mid, and full), approximately 12 fish of each species were released, between 1100 and 1200 hr, on each of three consecutive days. Low-pool releases began on April 11, mid-pool releases began on May 2, and full-pool releases began on May 23 in an attempt to meet pre-study target release pool elevations. Release of tagged smolts was a cooperative effort among participating agencies (USACE, MIT, and USFWS).

Fish were transported by truck from Keta Creek Hatchery to the release site in a 100-quart, oxygenated cooler. Because Howard Hanson Reservoir is within the City of Tacoma's municipal watershed, hatchery water in the transport cooler was replaced with Green River water at the Tacoma headworks (downstream of Howard Hanson Dam) before proceeding to the upper river release site. Water temperatures were monitored at the hatchery, the head works, and the release site to ensure fish were acclimated to temperature variations.

Monitoring

The monitoring period ranged from 18 to 20 d for low- and mid-pool releases, but up to 36 d for full-pool releases. To treat all monitoring periods equally, however, data collected after 20 d for the full-pool release were excluded from travel time analyses.

We assumed a 20-d monitoring period covered the bulk of the passage period of each release group. To test this assumption, we plotted all detections of each species at site W over time and qualitatively examined these distributions for evidence of migration after the 20-d monitoring period. These data were also summarized to describe diel movement pattern as an aid to fish passage design at Howard Hanson Dam.

Data Retrieval, Reduction, and Analysis

Retrieval and initial reduction of fixed receiver data were the responsibility of David Evans and Associates (DEA), Inc., a USACE contractor. DEA downloaded data and environmental files from field data loggers twice weekly. DEA sorted the data set and removed all records with any of the following characteristics:

- Signal strength ≤ 40.
- Pulse rate exceeding ± 2 ppm of expected value.
- No pulse rate or incomplete frequency.
- Inconsistent detection date/time (i.e., before the start date/time).
- Incorrect frequencies (e.g., all mid-pool release frequencies were removed from the full-pool data set, and vice-versa).
- Events recorded from a master or auxiliary antenna that did not define a location (i.e., all events recorded by the master antenna at site W were removed from mid- and full-pool data sets because only auxiliary antenna receptions at site W were considered valid for these releases).

We manually error-checked all reduced data files provided by DEA and recorded the first valid detection of each radio-tagged fish at sites M, W, and Z. Besides the error types listed above, we also removed all "ghost tag" frequencies from the data set. A "ghost tag" frequency was an erroneous detection by a receiver of a tag frequency, before its release, probably due to noise or interference in the 150 MHZ range at sites M and W.

MIT supplied all mobile tracking data to site W, which we incorporated into the fixed data set for travel time analysis.

Travel times from site A to sites M, W, and Z were computed for each fish by subtracting release date/time from its validated detection date/time. Differences in mean travel times among and between release groups were then tested with ANOVA. For most analyses of travel time in this report, site W data were emphasized because site W represented the "finish line." Moreover, fewer calibration and hardware problems were encountered at site W than the other sites, so detections at this site were considered more reliable than at the other sites (M and Z).

A preliminary analysis of release group travel times (using ANOVA, above) suggested that travel times for groups released at mid pool were greater than for groups released at either low or full pools. Thus, pool size, as originally hypothesized, did not in itself appear to adequately explain smolt travel time. To identify specific factors influencing smolt travel time in Howard Hanson Reservoir, a follow-up analysis of the data set (to site W) was conducted using generalized linear models (GLM). In the GLM analysis, a variety of environmental, physiological, and morphological variables associated with each tagged smolt were compared with each smolt's travel time. That is, estimates of travel time and related variables were unique to each fish. This further analysis was intended to help assess smolt travel time under existing and added reservoir storage conditions. Specific methods used in the follow-up GLM analysis, including a full description of variables used, are described in Appendix A (a detailed report of the entire GLM analysis).

RESULTS AND DISCUSSION

Overall, the slowest mean travel times to the dam's forebay (site W) for both species occurred during mid pool. Coho also moved through the reservoir more slowly than steelhead during mid and full pools (Figure 2). Specific results follow, including highlights of the GLM results described in detail in Appendix A.

For reference, Appendix B provides all available release and recovery information on each tagged fish, while Appendices C and D list specific morphological, physiological, and environmental values used in the GLM analysis.

Coho Travel Time

Of the 110 radio-tagged coho smolts released during the study, 62 were detected at site W. Travel times to site W ranged from 0.7 d (low pool) to 15.0 d (mid pool), while travel times to site M ranged from 0.4 d (low pool) to 18.3 d (full pool) (Table 1).

Mean travel time to site W at mid pool (11.0 d) was significantly greater ($P < 0.001$) than at either low pool (3.1 d) or full pool (6.0 d). Full-pool travel time was also significantly greater ($P = 0.006$) than at low pool. Again, travel times to site W at the three pool levels may not be entirely comparable because of the change in detection range at site W (reduced about 0.4 miles) after the low-pool release. This change in detection range could have increased the distance mid- and full-pool smolts traveled before detection at site W. The exact effect this change had on travel time is not possible to determine.

Additional factors that may have affected coho smolt travel times were WDFW's releases of large numbers of coho salmon and steelhead smolts in the reservoir during the study period. At site D (Figure 1), 20,000 coho salmon smolts and 60,000 steelhead smolts were released on April 24, and another 20,000 coho salmon smolts were released on May 9. The April 24 releases occurred largely between low- and mid-pool tests. The May 9 release, however, occurred during the mid-pool test, and thus could have affected this group by changing schooling behavior or by concentrating predators. Three radio tags (one from low-pool and two from mid-pool releases, Appendix B) were recovered on the stream bank near the release site, apparently the result of otter or bird predation.

Steelhead Travel Time

Of the 106 radio-tagged steelhead smolts released during the study, 76 were detected at site W. Travel times to site W ranged from 0.4 d (low pool) to 18.3 d (mid pool), while travel times to site M ranged from 0.2 d to 13.6 d (both at low pool) (Table 2).

Mean travel time to site W at mid pool (7.4 d) was significantly greater ($P < 0.001$) than at either low pool (2.9 d) or full pool (2.7 d), yet no significant difference was found between low-pool and full-pool travel times.

As mentioned above, the change in detection range at site W after the low-pool release may have artificially shortened travel times for low-pool releases, but the change does not explain the similarity in travel at low- and full-pool levels.

Large, non-study steelhead smolt releases were made by WDFW between low- and mid-pool tests on April 24 at site D. Given the relatively quick travel time of steelhead (compared with coho smolts), potential schooling and predation effects on steelhead travel time seem small. However, four steelhead radio tags (two from the low- and two from the full-pool releases, Appendix B) were recovered on the beach near the release site, apparently the result of otter or bird predation.

Coho Salmon versus Steelhead Smolt Travel Times

Mean travel time of coho smolts to site W (Figure 2) was significantly greater than that of steelhead smolts at mid pool ($P = 0.004$) and full pool ($P < 0.001$). No significant difference in travel time between coho salmon and steelhead smolts occurred at low pool. This suggests that, at increasing pool levels, coho smolts are slowed to a greater extent than steelhead, perhaps due to their smaller size and lesser swimming ability than steelhead smolts. In the lower Columbia River, coho smolts also traveled at half the rate of steelhead smolts (Ledgerwood et al. 1991).

The distributions of coho salmon and steelhead detections at site W (Figures 3 and 4, respectively) suggested that, if monitoring for a longer period (> 20 d) had occurred at low and mid pools, more coho salmon and steelhead might have been detected, especially at mid pool. For both species, peak detections occurred relatively early at low and full pools. However, at mid pool, peak detections occurred near the center of the recorded detections, suggesting that some level of additional detections would have occurred at the mid-pool level. This, in turn, could have increased mean travel times of both species at these pool levels.

Smolt Travel Time versus Environmental, Physiological, and Morphological Variables (GLM Analysis)

When release group was used as a predictor variable in the GLM analysis, travel time of coho salmon and steelhead smolts to site W was inversely related to reservoir inflow. Similarly, Moser et al. (1991) observed that travel time of coho smolts in the Chehalis River, Washington varied inversely with river flow, and that smolt movement was interspersed with extended periods of holding in areas of low water velocity. The latter observation could explain longer coho smolt travel times at mid- and full-pool levels in this work. Smolt travel time also varied inversely with river flow among hatchery and wild steelhead in the Columbia River basin (Berggren and Filardo 1993; Buettner and Brimmer 1995) and chinook salmon in the Willamette River, Oregon (Schreck et al. 1994).

When release group was not used as a predictor variable in the GLM analysis, travel time of coho salmon and steelhead smolts to site W varied directly with reservoir refill rate. This relationship could be explained by a decrease in flow through the reservoir during refill, causing an increase in smolt travel times, as noted above in other river systems.

As with the ANOVA results above, the GLM analysis also indicated that smolt travel times were longer for the mid-pool release group than the low- and full-pool release groups, and that coho smolts had longer predicted travel times than steelhead smolts. Lack of a monitoring station where the river changed to reservoir (this point constantly changed with reservoir elevation change), and lack of sequential fish releases throughout the study period, likely precluded a better explanation of the factors responsible for the observed changes in smolt travel times.

Emigration Timing

Natural variation in emigration timing should be considered if attempts are made to optimize smolt emigration to the dam by controlling refill rate (as suggested by the GLM analysis) during the emigration period.

In past studies, under low-pool conditions, coho salmon smolts passed Howard Hanson Dam from mid April to early June, with a peak in mid to late May (Seiler and Neuhauser 1985; Dilley and Wunderlich 1992). Steelhead smolts passed Howard Hanson Dam from late April to early June, peaking the first two weeks of May (Seiler and Neuhauser 1985). Holtby et al. (1989) found a similar two- to four-week window for 50% of the coho smolts emigrating from Carnation Creek, Vancouver Island, B.C.

Emigration timing of salmonids varies with changes in environmental conditions. Variations in emigration timing of spring chinook salmon smolts in the Columbia River Basin occurred as water temperature or river flow rates changed (Schreck et al. 1994; Achord et al. 1995; Buettner and Brimmer 1995). Holtby et al. (1989) also found water temperature variability accounted for 60% of the variability in the median date of coho smolt emigration from Carnation Creek. Changes in emigration timing of two weeks can reduce marine survival of coho salmon by as much as 50% (Bilton et al. 1982; Thedinga and Koski 1984).

Diel Timing

Of 62 radio-tag detections of coho salmon at site W (including detections not used in travel time analysis), 77% were logged during the day. Similarly, of 73 steelhead detections at site W, 70% were logged during the day. Table 3 shows that the majority of detections throughout all groups occurred during daytime, with the sole exception of steelhead released at low pool (26% daytime, 74% nighttime). Here, day was defined as sunrise to sunset, where sunrise ranged from 0500 - 0619 hr and sunset ranged from 1944 - 2103 hr over the course of the study.

Figure 5 shows the distribution of these detections and suggests a peak for coho salmon in the late afternoon and a peak for steelhead around midday. These data are only times of detection, and true diel movement would have to be confirmed with continuous mobile tracking.

A preponderance of daytime "movement" was also reported in radio-tag studies conducted by Moser et al. (1991) on coho salmon and Ledgerwood et al. (1991) on coho salmon and steelhead.

Migratory Tendency of Radio-tagged Smolts

Migratory tendency, as indicated by mean ATPase level, was high in both coho salmon and steelhead smolts throughout the study (Zaugg 1995).

Based on ATPase levels, coho smolts showed good migratory ability at time of low- and mid-pool releases, but a drop in ATPase level (below pre-study values) occurred with the full-pool release (Table 4). This latter drop, however, was not significant and should not have affected performance (Zaugg 1982b, 1995).

Mean weights and lengths of coho salmon sampled for ATPase were significantly smaller than coho smolts that were radio tagged ($P < 0.05$)

(Table 4). This difference probably occurred because larger individuals were purposely selected for radio tagging. Although larger, the radio-tagged fish were still within a normal size range for smolts, so their ATPase level and migratory disposition were probably similar to coho used for ATPase analysis.

Steelhead ATPase levels were well developed in all release groups, with mid- and full-pool fish exhibiting slightly greater levels than low-pool fish (Table 5). Under equal conditions, the mid- and full-pool fish may have migrated faster than low-pool fish, but all three groups should have performed well, according to Zaugg (1995).

Mean weights and lengths of steelhead sampled for ATPase in the low- and mid-pool release groups were significantly smaller than fish used for radio tagging ($P < 0.05$), but full-pool groups were not significantly different (Table 5). As with coho smolts, this difference probably occurred because larger individuals were purposely selected for radio tagging. Individuals used for radio tagging, however, were still within a normal size range for steelhead smolts, so their ATPase level and migratory disposition were probably at least comparable, if not greater, than those measured for ATPase.

Tag Recovery Rates

Tag recovery rates, or percentages of released fish detected by a receiver at sites M and W, are shown in Table 6. Tag recovery rates are at best conservative estimates of survival. As Schreck et al. (1994) state, radio-tag recovery rates should be considered minimum survival values because, "1) even with the best radio reception some transmitters may not be heard, 2) some transmitters could fail during the outmigration, and 3) some transmitters could be regurgitated."

Tag recovery rates for coho salmon, at site W, ranged from 56% at low pool, to 39% and 74% at mid and full pools, respectively. Tag recovery rates for steelhead at site W ranged from a low of 53% at low pool, to 75% and 88% at mid and full pools, respectively (Table 6). One reason for low recovery rates could be residualism, which ranged from 3-18% for hatchery-reared steelhead released into the Tucannon River, Washington (Viola and Schuck 1995). Other factors include mortality of the tagged fish due to predation, and mortality or delay from transportation and handling (Piper et al. 1982). Overall, however, tag recovery rates were similar to those reported for radio-tagged chinook smolts in the Willamette River, Oregon (Schreck et al. 1994).

Tag recovery rates to site Z below the dam (Figure 1) ranged from 17% at low pool to 0% at mid and full pools for each species. Lack of detections at mid and full pools was consistent with earlier emigration studies (Dilley and Wunderlich 1992, 1993), which suggested that coho and steelhead smolt passage through Howard Hanson Dam is very poor after refill commences. Tags, however, may have been damaged during passage through the dam, thereby affecting tag detection at site Z.

Effects of Mobile Tracking Data

Incorporating mobile tracking data into the fixed receiver data for site W effectively shortened the mean travel time of coho salmon by 0.7 d and increased the mean travel time of steelhead by 0.4 d. Five new coho and three new steelhead receptions were added to the data set, and travel times of eight coho salmon were shortened. Appendix B shows where mobile tracking data were incorporated in the fixed receiver data set.

Tag Versus Fish Size

Excessive tag weight (or size) may adversely affect fish behavior in radio-tagging studies. Moser et al. (1990) reported that dummy transmitters representing up to 4.7% of body weight (air weights) did not adversely affect swimming or behavior of coho smolts, although they recommended a 4-hr post-tagging recovery period to allow for buoyancy compensation and possible regurgitation. They also reported that coho smolts were not adversely affected by tags representing 4.5-14.5% of the fish's body weight.

In this study, radio tagging should not have adversely affected smolt performance. Tag size and weight were within the recommendations of Moser et al. (1990). Tag-to-smolt weights (air weights) ranged from 2.2% to 5.7% for coho smolts, and from 1.7% to 4.8% for steelhead smolts.

In this study, tag regurgitation was also not likely a problem. Moser et al. (1990) reported that if fish did not regurgitate a tag within 4 hr, the fish would probably retain the tag for at least a week or more. For coho smolts in this work, the 24-hr tag-retention rates for each group were 95% (low-pool), 98% (mid-pool), and 100% (full-pool). For steelhead smolts, the 24-hr tag-retention rate was 100% for all groups.

CONCLUSIONS

We conclude the following:

1. Mean travel times of coho and steelhead smolts were greater at mid pool than at either low or full pools.

2. Mean travel times of coho smolts passing through the Howard Hanson Reservoir were significantly greater than steelhead smolts at both mid and full pools, suggesting that coho smolts had more difficulty than steelhead smolts in navigating the reservoir as it increased in size.

3. Radio-tagged coho salmon and steelhead smolts were potentially highly migratory at time of release based on ATPase activity, and there was no evidence that radio tagging adversely affected smolt behavior or performance during the study.

4. A GLM model (Appendix A) suggested that travel times of coho and steelhead smolts to site W were inversely related to inflow, when release group (low-, mid-, and full-pool releases) was used as a predictor variable.

5. The GLM model also suggested that, when release group was not used as a predictor variable, a weak direct relationship existed between smolt travel times and refill rate.

6. No radio-tagged coho salmon or steelhead smolts were detected passing Howard Hanson Dam after refill began, suggesting that smolt passage through the dam is very poor at elevated reservoir levels.

RECOMMENDATIONS

Based on these findings, we recommend:

1. If refill rate controls smolt travel time, as is weakly suggested by the GLM model, then additional study is needed to 1) strengthen this conclusion, and 2) determine what range of refill rates are detrimental to smolt emigration. Refill rate is important because it can be manipulated through dam operation.

2. If this radio-tag evaluation is repeated, it should incorporate:

    a. Modeling to determine the optimal number of transmitters and the best release protocol, such as releasing fish daily or weekly. This should improve study results by exposing the tagged fish to a broad range of environmental conditions during the emigration period.

    b. Continuous mobile tracking of individual fish for 12-24 hr to better describe their migration routes and behavior in the reservoir.

    c. Removing the riverine aspect of the study by releasing and monitoring the fish at the slack water line of the reservoir.

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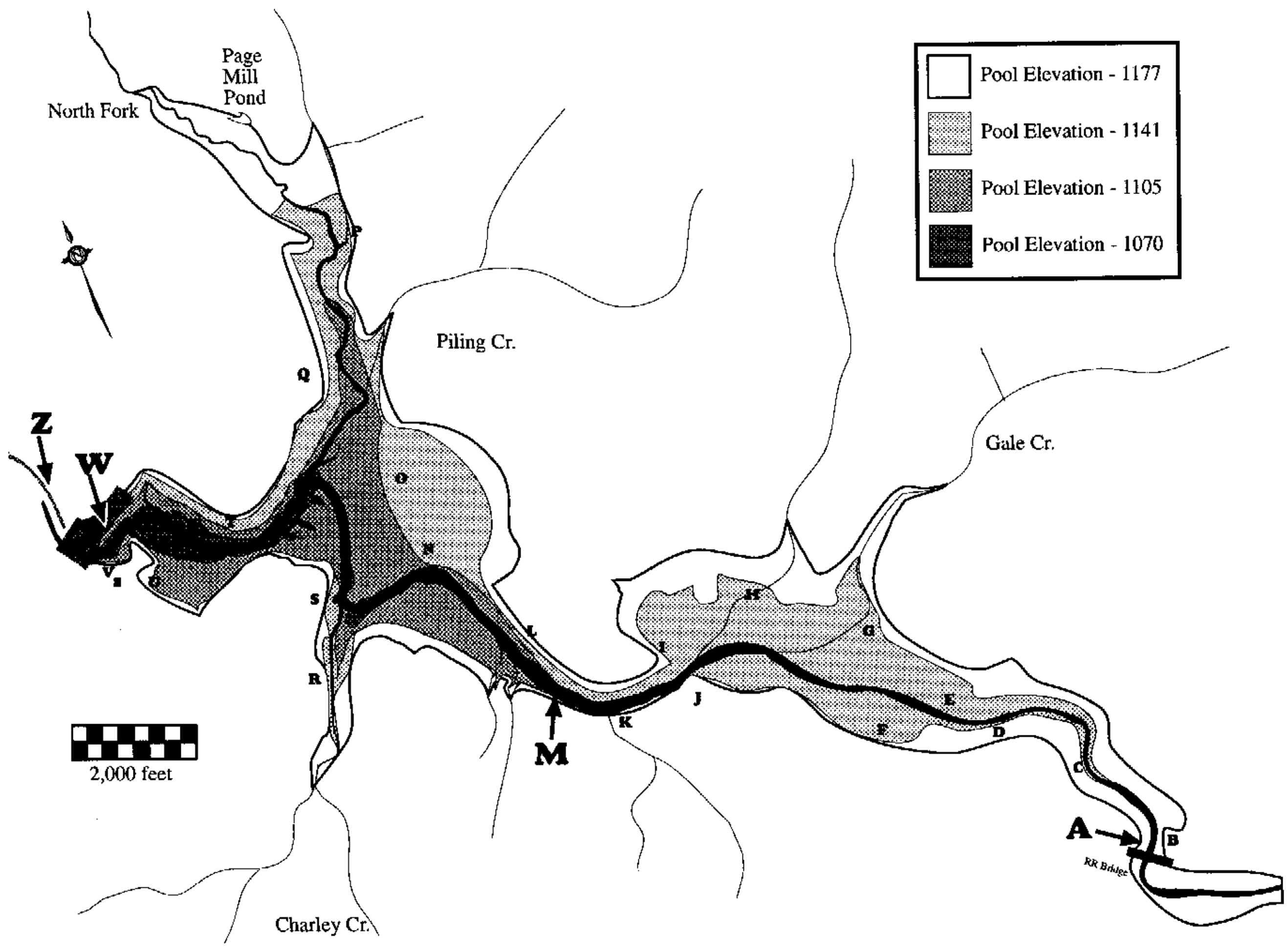

Figure 1. Howard Hanson Reservoir at low, mid, full, and added-storage pools. Letters indicate fixed and mobile radio-tracking sites. (Figure credit: Eric Warner, MIT)

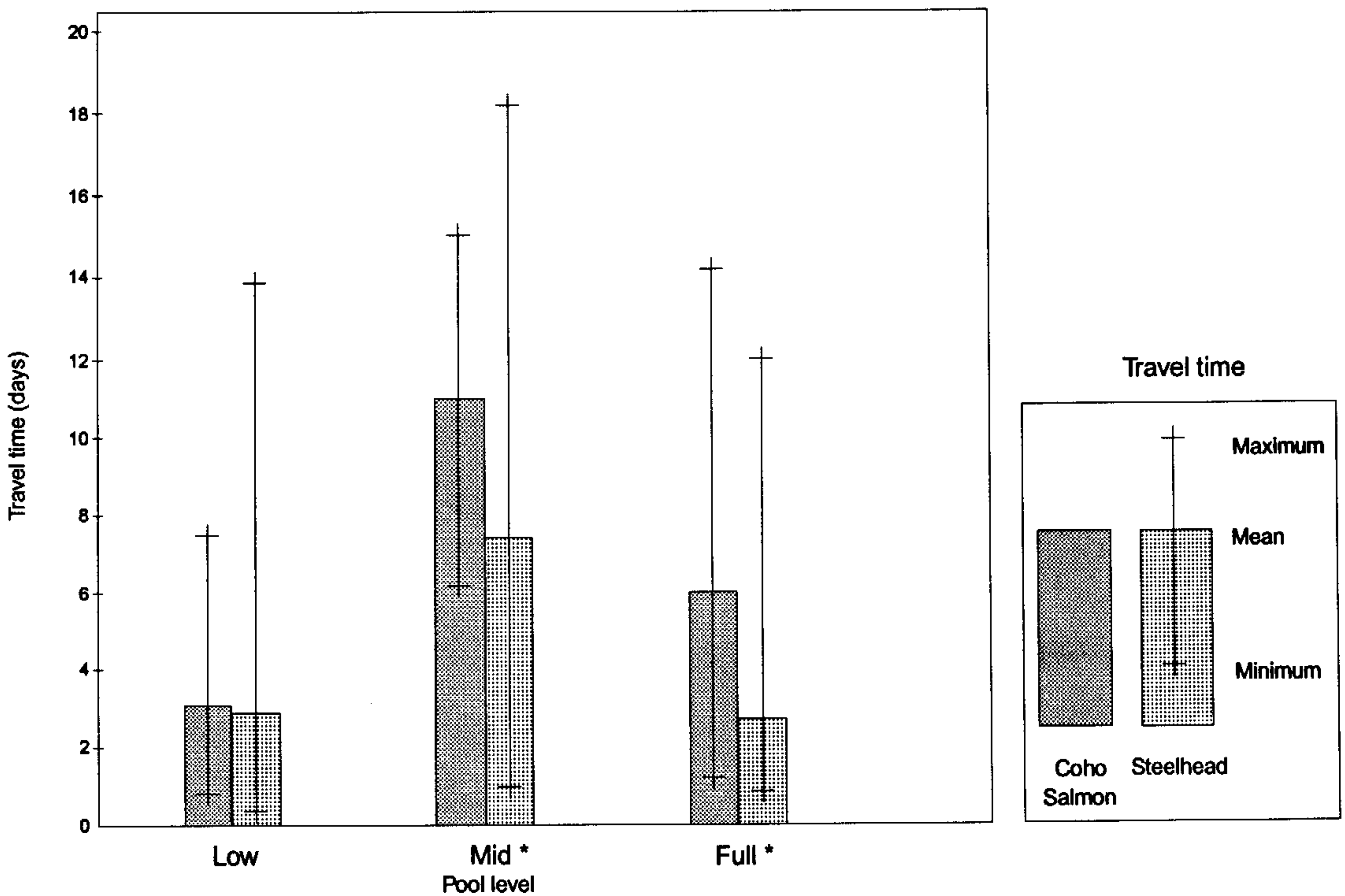

Figure 2. Maximum, mean, and minimum smolt travel times to site W. Asterisks indicate significant ($P < 0.05$) differences between species.

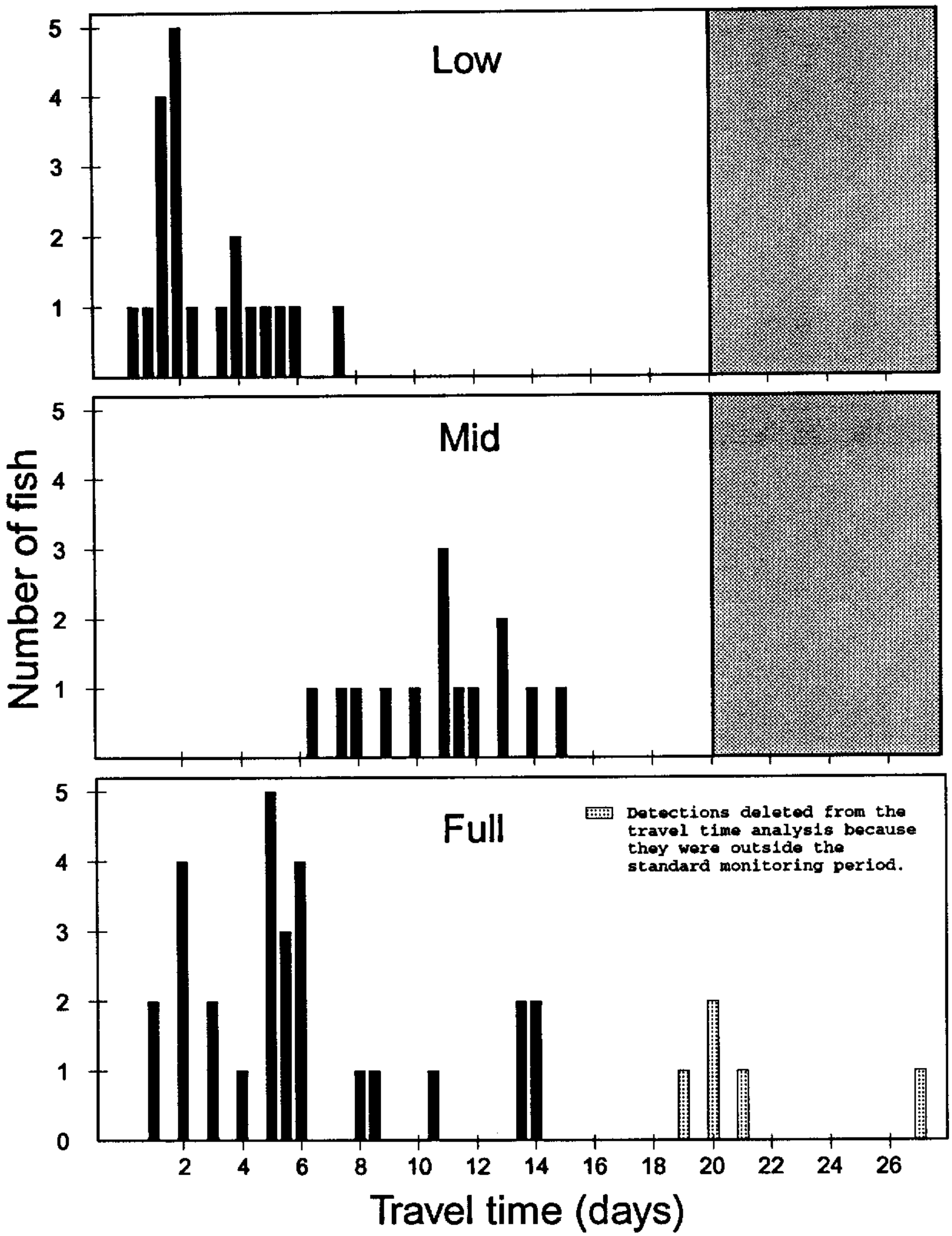

Figure 3. Frequency histogram of coho salmon travel time to site W at low, mid, and full pools. No monitoring occurred during the shaded time periods.

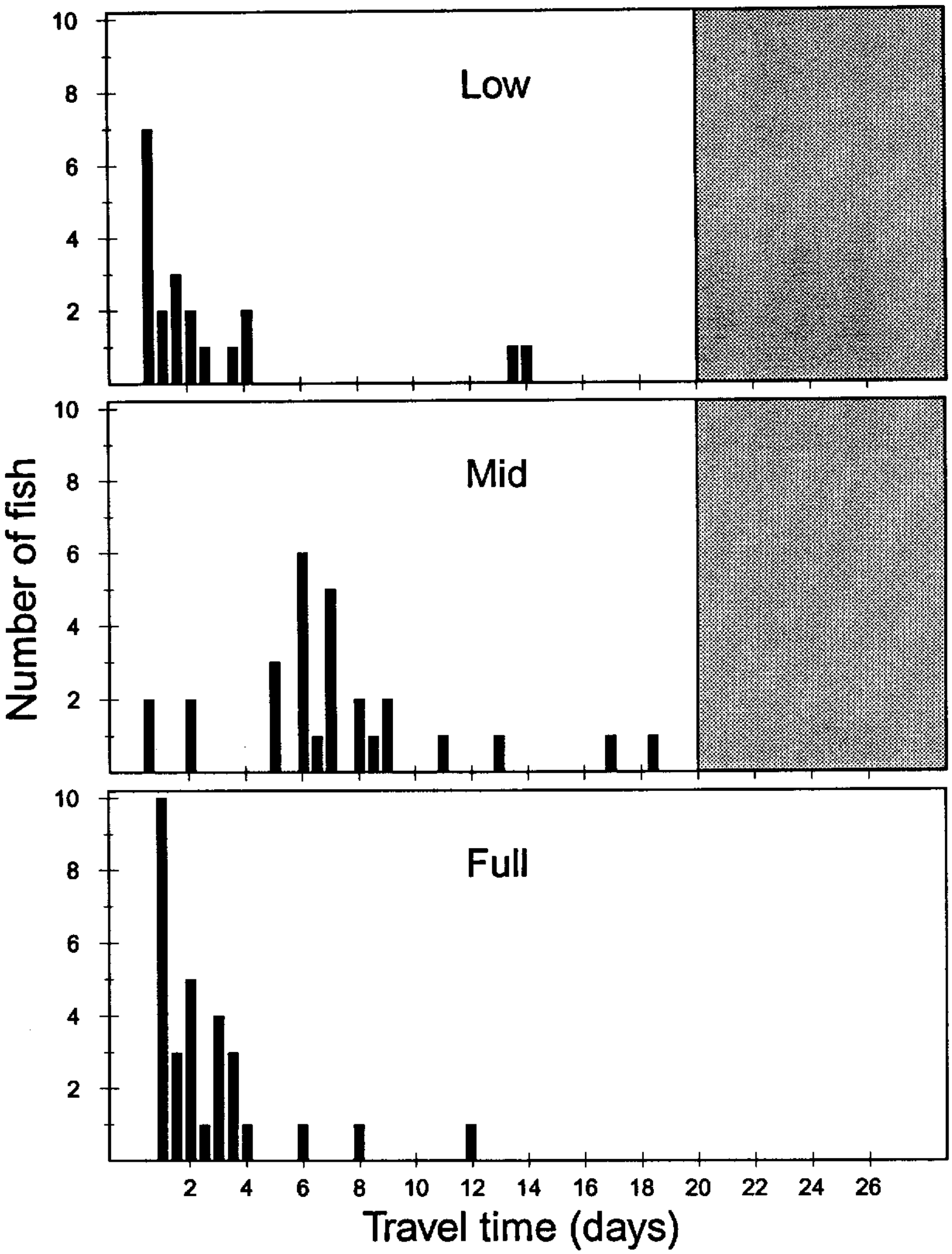

Figure 4. Frequency histogram of steelhead travel time to site W at low, mid, and full pools. No monitoring occurred during the shaded time periods.

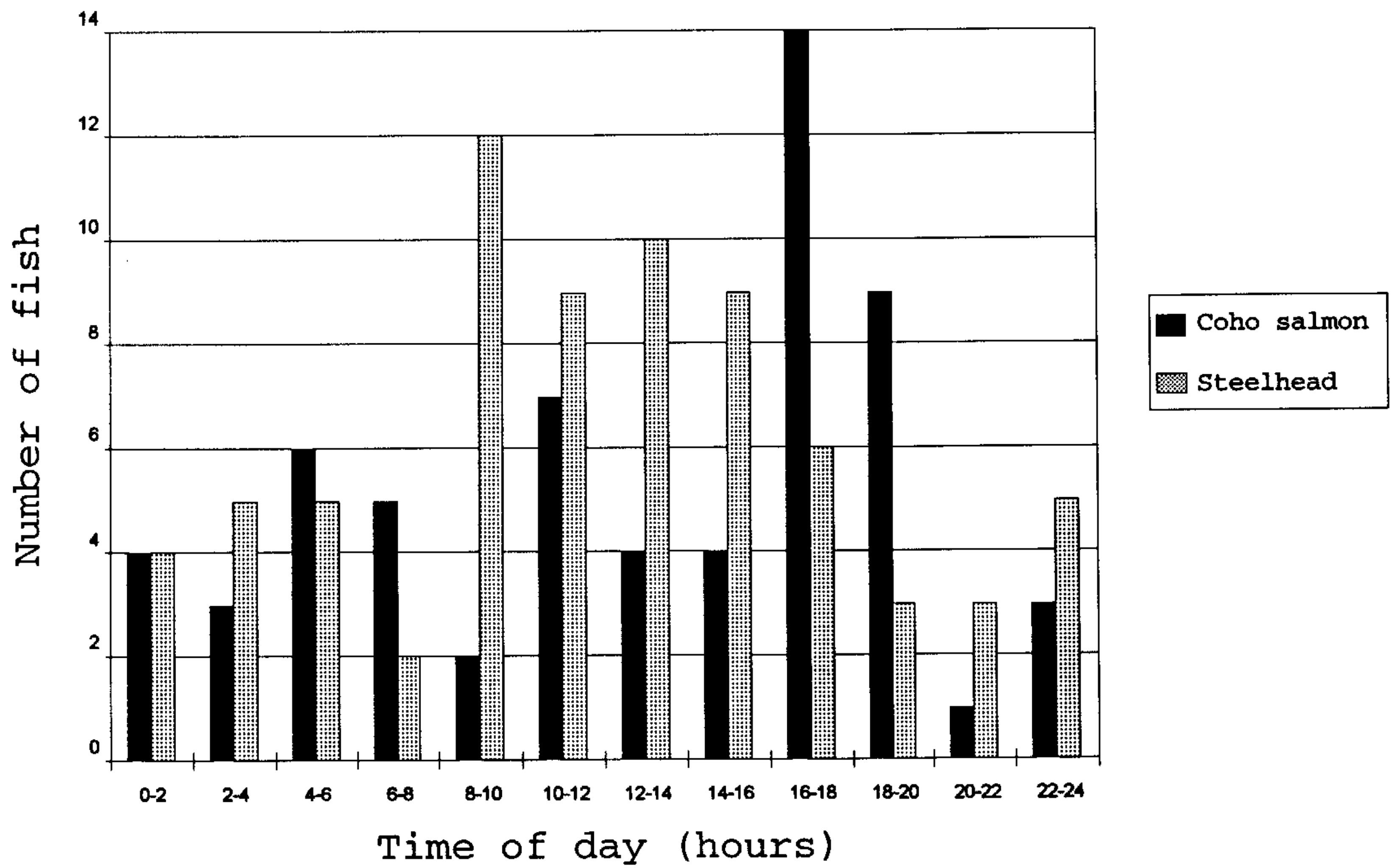

Figure 5. Diel timing of smolt detection at site W using all available fixed receiver data.

Table 1. Travel time of coho salmon, in days, from release site A to the fixed receiver sites.

	Low pool	Mid pool	Full pool
Fish tagged and released	36	36	38
		Travel time to M [A]	
n	27	10	22
mean	1.9	5.7	3.1
SD	2.7	2.8	5.0
max.	13.3	8.4	18.3
min.	0.4	1.7	0.6
median	0.8	7.0	0.9
		Travel time to W [A B]	
n	20	14	28
mean	3.1	11.0	6.0
SD	1.9	2.6	3.9
max.	7.6	15.0	14.2
min.	0.7	6.3	1.1
median	2.2	11.1	5.2
		Travel time to Z [C]	
n	6		
mean	7.8		
SD	7.1		
max.	19.5		
min.	1.7		
median	6.4		

[A] Travel times reflect equal monitoring periods at all pool levels.

[B] Travel times incorporate mobile tracking data.

[C] No mid- or full-pool releases were detected at site Z.

Table 2. Travel time of steelhead, in days, from release site A to the fixed receiver sites.

	Low pool	Mid pool	Full pool
Fish tagged and released	36	36	34
		Travel time to M [A]	
n	25	11	30
mean	1.1	4.5	2.0
SD	2.7	2.5	2.2
max.	13.6	7.1	10.2
min.	0.2	0.7	0.6
median	0.4	5.1	0.9
		Travel time to W [A,B]	
n	19	27	30
mean	2.9	7.4	2.7
SD	4.0	3.9	2.4
max.	13.8	18.3	12.0
min.	0.4	0.9	0.8
median	1.4	6.9	2.0
		Travel time to Z [C]	
n	6		
mean	8.8		
SD	6.1		
max.	17.2		
min.	2.6		
median	8.0		

[A] Travel times reflect equal monitoring periods at all pool levels.

[B] Travel times incorporate mobile tracking data.

[C] No mid- or full-pool releases were detected at site Z.

Table 3. Diel timing of smolt detections at site W, where day was sunrise to sunset.

	Coho salmon detections		Steelhead detections	
	Day (%)	Night (%)	Day (%)	Night (%)
Low pool	12 (60)	8 (40)	5 (26)	14 (74)
Mid pool	8 (80)	2 (20)	22 (92)	2 (8)
Full pool	28 (88)	4 (12)	24 (80)	6 (20)
Total	48 (77)	14 (23)	51 (70)	22 (30)

Table 4. ATPase levels, lengths, and weights of coho salmon.

	ATPase level[A]	Fork length (mm)		Weight (g)	
		ATPase fish[B]	Tagged fish[C]	ATPase fish[B]	Tagged fish[C]
			Low pool		
n	15	15	36	15	36
mean	15	131	142	23	28
SD	2	6	10	2	7
max.	18	142	175	28	55
min.	12	120	130	20	22
			Mid pool		
n	15	15	36	15	36
mean	14	133	139	26	31
SD	4	7	7	4	5
max.	23	149	164	36	50
min.	10	121	130	20	25
			Full pool		
n	15	15	38	15	38
mean	9	131	135	25	27
SD	2	4	3	3	2
max.	15	136	143	30	33
min.	7	125	130	22	21

[A] µmoles ATP hydrolyzed per mg protein per hour.

[B] Fish sacrificed from the release group population for ATPase measure.

[C] Fish used for radio tagging.

Table 5. ATPase levels, lengths, and weights of steelhead.

	ATPase level[A]	Fork length (mm)		Weight (g)	
		ATPase fish[B]	Tagged fish[C]	ATPase fish[B]	Tagged fish[C]
			Low pool		
n	15	15	36	15	36
mean	19	181	193	60	72
SD	7	13	10	11	11
max.	39	200	214	79	97
min.	13	158	170	41	50
			Mid pool		
n	15	15	36	15	36
mean	24	190	200	71	82
SD	5	13	14	15	17
max.	33	210	236	101	132
min.	17	163	173	44	48
			Full pool		
n	15	15	34	15	34
mean	24	193	195	74	77
SD	6	6	13	7	16
max.	34	204	224	90	114
min.	14	182	174	64	54

[A] µmoles ATP hydrolyzed per mg protein per hour.

[B] Fish sacrificed from the release group population for ATPase measure.

[C] Fish used for radio tagging.

Table 6. Tag recovery rates at sites M and W for all release groups of coho salmon and steelhead smolts.

	Pool level / release date											
	Low pool				Mid pool				Full pool			
	Apr 11	Apr 12	Apr 13	total	May 2	May 3	May 4	total	May 23	May 24	May 25	total
Coho salmon to site M												
Tags released	12	12	12	36	12	12	12	36	12	12	14	38
Tags recovered	11	8	8	27	6	4	0	10	10	9	3	22
Percent	92	67	67	75	50	33	0	28	83	75	21	58
Steelhead to site M												
Tags released	12	12	12	36	12	12	12	36	12	12	10	34
Tags recovered	10	7	8	25	4	4	3	11	10	12	8	30
Percent	83	58	67	69	33	33	25	31	83	100	80	88
Coho salmon to site W												
Tags released	12	12	12	36	12	12	12	36	12	12	14	38
Tags recovered	7	7	6	20	6	4	4	14	12	11	5	28
Percent	58	58	50	56	50	33	33	39	100	92	36	74
Steelhead to site W												
Tags released	12	12	12	36	12	12	12	36	12	12	10	34
Tags recovered	8	5	6	19	9	10	8	27	11	12	7	30
Percent	67	42	50	53	75	83	67	75	92	100	70	88

Appendix A.

Evaluation of Hatchery Coho Salmon and Steelhead Smolt Travel Time through Howard Hanson Reservoir with Generalized Linear Models

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ABSTRACT

The effects of various environmental, physiological, and morphological factors on the travel time of hatchery coho salmon *(Oncorhynchus kisutch)* and steelhead *(O. mykiss)* smolts in Howard Hanson Reservoir were analyzed using generalized linear models (GLM). The ratio of outflow to inflow and refill rate of the reservoir were the most important variables followed by fish weight and outflow turbidity in explaining travel times when release group (low, mid, and full pool releases) was not used as a potential predictor variable in building a model. Smolt travel time was inversely related to the ratio of outflow to inflow and fish weight. This model had an R^2 value of 0.47. When release group was used as a factor, it was the most important variable in explaining travel time, followed by average inflow and one of these variables: ATPase level, forklength, fish weight, and species. Smolt travel time was inversely related to inflow, ATPase level, forklength, and fish weight. Both coho and steelhead salmon smolt travel times were longer for the mid-pool release group than for low- and high-pool release groups, and when species was used as a predictor variable in a model containing release group and inflow, coho salmon had longer predicted travel times than steelhead. The models developed with release group as a factor had R^2 values ranging from 0.83 to 0.84. Other undetermined factors, which may include time spent in river, and predator and prey abundance, have likely caused models with release group to better explain travel times than models without release group. Given the variables that were used to develop the above models and likely unrecorded differences in experimental conditions between the pool levels, we are not confident in predicting travel time under the proposed additional reservoir storage.

INTRODUCTION

Travel times of radio-tagged coho salmon and steelhead smolts were found to be significantly different among three reservoir pool levels (low, mid, and full) examined in the 1995 radio-tag study of smolt passage through Howard Hanson Reservoir, based on an analysis of variance. A Tukey's studentized range test determined travel times for smolts released during mid pool to be longer than travel times for smolts released at low and full pool. Therefore, pool size, as a class variable, was found to be an insufficient linear descriptor of smolt travel time in this reservoir. An analysis using generalized linear models (GLM) with various environmental, physiological, and morphological variables was conducted to identify factors influencing smolt travel time in Howard Hanson Reservoir. Identification of these factors could also help assess smolt travel time with added reservoir storage.

Models have been developed to help assess hydrosystem impacts and offer insight into potential management actions to improve fish passage and survival through a river system (Lee, 1991). Generalized linear models have been used to model fish survival rates as a function of various factors or covariates, including when statistical dependence most likely exists (Green and MacDonald, 1987; Cormack and Skalski, 1992; Pascual et al., 1995; Newman, 1995). Models (non GLM) have also been developed to describe juvenile migration of salmon and steelhead (Lee, 1991; Smith et al., 1993). These models, such as FISHPASS (Tanovan, 1985), System Planning Model (Northwest Power Planning Council, 1989), CRiSP (developed at the Center for Quantitative Science at the University of Washington), and a model developed by Lee (1991), simulate mortality and downstream migration through the Columbia River system.

The travel time data analysis in this paper differs from previous travel time analysis (Smith et al., 1993) in four ways: 1) estimates of the travel time and environmental variables are unique to each fish, rather than to an entire release group, 2) smolt travel included both riverine and reservoir conditions, 3) more than 30 variables were considered as potential predictors of smolt travel times, rather than a select few, and 4) no estimates or inferences regarding mortality rates were determined.

METHODS

Data

Of the 110 coho salmon and 106 steelhead tagged in the 1995 radio-tag study, data on travel time from release (4.6 miles upstream from the dam) to the dam were available for 62 coho salmon and 76 steelhead. Travel times were obtained using fixed receivers and mobile tracking data. Factors considered in predicting fish travel time included fish species (SP), forklength (FL), weight (WT), K-factor (K), ATPase level (ATP), and environmental factors. The environmental variables used in the analyses include reservoir content (C), surface area (SA), refill rate (RR), pool elevation (PE) and elevation change (ΔPE), inflow (IF), outflow (OF), the ratio of outflow to inflow (OF/IF), inflow turbidity (IT), outflow turbidity (OT), temperature (T), and water particle travel time (WPTT) from the release site to the dam (Table 1).

Environmental data for individual fish were generated by calculating the averages of the available environmental measurements (hourly or daily) over the fish's travel time (Appendix C). For example, if a fish was released on day 10 and arrived at the dam on day 12, the environmental values assigned would be the averages of the variables between and including the 10th and the 12th days. ATPase levels used were a surrogate measure of the degree of smoltification of a group per day of release. Fish were assigned the average

ATPase level (by species) of the group sampled for ATPase on the tagging day of the fish.

Models

A GLM is a linear predictor based on a linear combination of explanatory variables (McCullagh and Nelder, 1989). Generalized linear models have a common algorithm for the estimation of parameters by maximum likelihood. This algorithm uses weighted least squares with an adjusted dependent variate. Generalized linear models do not depend on normality and constancy of variance and the models can handle both continuous and categorical data, as well as a mixture of the two. The set of potentially appropriate distributions in describing travel time through a reservoir includes the exponential, lognormal, gamma, Weibull, and inverse Guassian (Lee, 1991). The gamma probability function was chosen because travel time data, being essentially waiting time data, are typically modeled with the gamma distribution (μ $(0,\infty)$). Waiting time data, or data following a gamma distribution, are always positive and the distribution of values is skewed to the left (with travel times, one would expect a higher number of smaller values, with fewer and fewer fish returning as time passes). When utilizing the gamma probability function, the canonical link is $n = \mu^{-1}$ and values of n must never be negative. If they are, a GLM analysis will fail. The analysis in this study did yield negative values of n (or negative travel times), thus a gamma distribution with a log-link was used in the GLM analysis. We have no *a priori* reason to believe the factor (variable) effects in the models should be additive. Biological intuition suggests the factor effects are multiplicative. That is, the resultant effect of a change in one factor should have a proportional effect on the estimate of travel time, rather than an incremental additive effect. Therefor, the log-link was also selected to convert the multiplicative effects in the model to an additive structure.

Generalized linear models of the travel time data were developed using SASS, SPLUS and XLISP-STAT. First, pairwise linear correlations were determined between the independent variables and travel time and among the environmental, physiological, and morphological (independent) variables. Stepwise forward selection and backward elimination for adding or dropping factors were employed in developing the models. The criterion for adding or deleting an independent variable was the F statistic at a p-value of 0.05. The AIC statistic (Newman, 1995) and the C_p criterion (Zar, 1984) were used in determining the "best" models. The AIC statistic is a function of the degree of model misfit and complexity. Model misfit is measured by the deviance and model complexity is measured by the number of parameters in the model. An overly complex model is penalized in computing the AIC statistic. The C_p criterion is a function of the total mean squared error of the fitted values and can be used as a measure of the model's bias. In both the AIC statistic and the C_p criterion, one seeks to identify subsets of predictor variables for which these values are small. Residual plots were also examined for all models presented in this paper.

Release group was not used initially as a predictor variable because it was assumed the variation in environmental, physiological, and morphological variables among and between the release groups would sufficiently explain smolt travel times. When the best model without release group as a variable was found to poorly explain smolt travel time, release group was added as a predictor variable.

RESULTS

The pairwise linear correlations between travel time and all the potential predictor variables are listed in Table 2. The variables pertaining to reservoir refill, such as the ratio of outflow to inflow, refill rate, and the difference between outflow and inflow, have the highest correlations with travel time besides release group. The reservoir refill variables are highly correlated, as are the physiological and morphological variables, such as weight, length, K-factor, and ATPase level, and environmental variables, such as pool elevation, surface area, content, and water particle travel time.

Model 1 - without Release Group

Using stepwise, forward selection a model containing the ratio of outflow to inflow (OF/IF), fish weight (WT), and outflow turbidity (OT) was developed when release group (RG) was not used as a potential predictor variable (Table 3). The best subsets regression analysis yielded the same model. The three best models including 1, 2, or 3 variables are listed with respective values for R^2, AIC, and the C_p criterion in Table 3. Table 4 gives detailed results from the best 2- and 3-variable models. The coefficients for the ratio of outflow to inflow (OF/IF), fish weight (WT), and outflow turbidity (OT) are negative, suggesting as the ratio of outflow to inflow, fish weight, and outflow turbidity increases, smolt travel time decreases. When refill rate (RR), which is highly negatively correlated (0.95) with the ratio of outflow to inflow (OF/IF), was used as a predictor variable, the coefficients indicate that smolt travel time increases as refill rate (RR) increases.

Model 2 - with Release Group

The stepwise procedure selected the variable release group (RG) first, followed by average inflow (IF), and then ATPase level (ATP). The best subsets regression analysis yielded the same model. The best models including 1, 2, 3, or 4 variables are listed with respective values for R^2, AIC, and the C_p criterion in Table 5. Smolt travel time was found to be inversely related to inflow, ATPase level, forklength, and fish weight. Coho travel times, when species was used as a predictor variable, were determined to be longer than the travel times for steelhead (Table 5 (c-4)). There are several 3-variable models and one 4-variable model that are nearly equal in their explanatory power. The choice of one of them would depend on the ease of interpretation and the use of the model. Table 6 gives detailed regression results from the best 2- and 3-variable models. The coefficient for release group (RG), low pool, is zero because the coefficients of class variables are scaled to the first class variable entered into the model. In all of the best models in Table 5, the release group (RG) mid pool has positive coefficients, meaning the fish in this group had longer travel times than RG (low pool). Release group (RG) high pool has a negative coefficient, therefore, this release group traveled quicker from the release site to the dam than release group (RG) low pool. The coefficients for average inflow (IF) and ATPase level (ATP) in the models suggest that greater inflows and higher ATPase levels are associated with shorter travel times.

Model Comparisons

Observed versus fitted (predicted) values for the chosen "best" models with and without release group as a potential predictor variable are shown in Figure 1.

DISCUSSION

Release Group and Travel Time

Using release group as a class variable yielded a much better model fit. This suggests that there are many unknown or unmeasured factors (environmental, physiological, or morphological) affecting fish movement in this system.

Inflow and Travel Time

The best variable in explaining travel times in this study, once release group was taken into account, was average inflow. As inflow increased, travel times decreased. Inverse flow volumes were also found to relate to chinook travel times in the Snake River (Smith et al., 1993). Taking the inverse of inflow did not yield a greater fit or a higher correlation in the Howard Hanson study, but this may be due to insufficient fish data or lack of variability in inflow.

Outflow and Travel Time

The best predictors of travel time data, when release groups were not taken into account, were measures of refill rate. The models developed suggest that as refill rate increases, smolt travel time increases. Other models also suggest as inflow increases, smolt travel time decreases. These, seemingly opposite responses, may be better described or modeled if more diverse outflow data were available during the study. Outflows, though different between release groups, remained fairly constant within a release group during the study, offering little more information than the class variable release group (RG) as a predictor variable. This lack of diversity in outflow data was because of the low water year in 1995, where inflow was approximately 70% of normal. Experiments manipulating outflows may resolve some of the effects of outflow as it relates to inflow and travel time, but with the fish unable to exit at the surface of the dam, there will again be an unmeasurable dam effect on smolt travel time. Even with no surface exit, outflow manipulation as it relates to travel time would be a highly important experiment, especially now that measures to manipulate outflow to improve smolt travel times have been proposed.

Unknown Variables and Travel Time

It appears that apart from the inflow and refill rate differences, there must have been unrecorded differences in experimental conditions from pool level to pool level. For example, differences most likely occurred between release groups in predator and prey abundance, which have been known to affect an animal's behavior and movement (for example on effects of prey abundance see Bax (1983); and predator effects see Abrahams and Healey (1993)). In addition, a large percentage of coho (44%) and steelhead (28%) died or were not detected by receivers. Whether these fish died due to environmental conditions that varied between release groups or just went undetected is unknown and a relationship between these missing fish, their release group, and travel times is undetermined.

Travel Time Data

Ideally, one would like to obtain separate travel time data for the time fish spent in river and the time spent in the reservoir, as most of our independent variables do not pertain to both environments. Unfortunately, this was not possible because it was not feasible to put an automatic data logger at the edge of the constantly changing pool. Because we do not know how much time a fish spent in the river, we are assuming the smolts spent the majority of their travel time in the reservoir. This assumption may indeed be valid for coho but may not be for steelhead. The proportion of travel how much time a fish spent in the river, we are assuming the smolts spent the majority of their travel time in the reservoir. This assumption may indeed be valid for coho but may not be for steelhead. The proportion of travel time to site M (midway point from the release site to the dam) of total travel time is greater than 0.50 for the majority of steelhead in all release groups. These findings may be an artifact of inadequate monitoring at site M (which also was a less powerful monitoring station than W, and lacked calibration of antenna direction, gain, etc.), or steelhead tended to remain near the release point longer than coho and were subjected to riverine conditions longer. Without knowing when a fish moved from riverine to reservoir conditions, and not knowing the unrecorded differences in experimental conditions from pool level to pool level, we are not confident in predicting travel time under the proposed additional reservoir storage with our models.

CONCLUSIONS

In summation, our major conclusions are:

1. The relationships between smolt travel time and environmental, physiological, and morphological predictor variables in the models have poor resolutions, but can be used as general descriptors.

2. Various flow measurements were found to be the most important environmental variables available in explaining radio-tagged coho salmon and steelhead smolt travel time through Howard Hanson Reservoir.

3. When release group was not used as a predictor variable, reservoir refill measurements, such as refill rate, the ratio of outflow to inflow, and the difference between inflow and outflow were the highest correlated variables to smolt travel time. Travel times increased as refill rate increased.

4. When release group was used as a predictor variable, inflow was found to explain most of the variability of travel times between the three groups (low, mid, and full pool). Travel times decreased as inflow increased.

5. Results suggest an inverse relationship between travel time and variables such as fish weight, ATPase levels, forklength, outflow turbidity, and inflow turbidity.

6. Both coho salmon and steelhead smolt travel times were longer for the mid-pool release group than for low- and high-pool release groups.

7. When species was used as a predictor variable in a model containing release group and inflow, coho salmon had longer predicted travel times than steelhead.

8. Without knowing when a fish moved from riverine to reservoir conditions, and given the variables that were used to develop the above models and likely unrecorded differences in experimental conditions between the pool levels, we are not confident in predicting travel time under the proposed additional reservoir storage.

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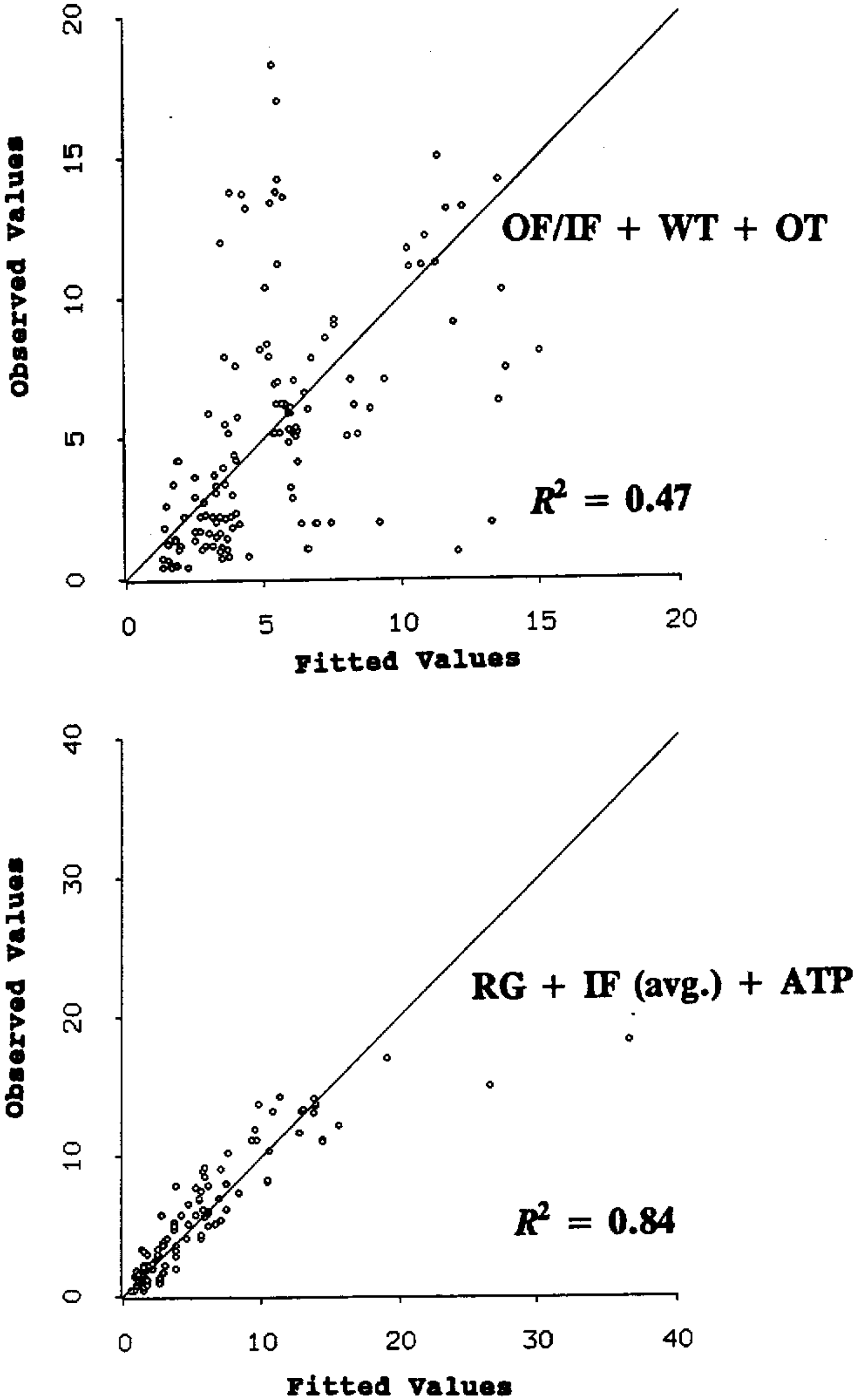

Figure 1. Observed versus fitted values of smolt travel time for models selected by stepwise regression without release group (upper panel) and with release group (lower panel) as a predictor variable. A perfect model would produce fitted values on the line drawn.

Table 1. The independent variables used in developing the generalized linear models to explain smolt travel time of coho salmon and steelhead through the Howard Hanson Reservoir.

	Variables	Description
(SP)	Species	Coho salmon or steelhead.
(FL)	Forklength (mm)	Measured at time of tagging.
(WT)	Weight (g)	Measured at time of tagging.
(K)	K-factor (g/L^3)*100,000	Fish condition measured by fish length and weight at time of tagging.
(ATP)	ATPase (µmoles/mg/hr)	5 fish were sampled for ATPase levels per species per tagging day, for a total of 15 fish per species per release group.
(RG)	Release group	3 releases of approximately 36 fish of each species, 18-20 days apart. The release strategy was an attempt to subject fish to low-, mid-, and full-pool conditions.
(C)	Content (acre-feet)	Water volume of reservoir based on graphically-measured surface areas and gage-measured instantaneous pool elevations. Conic section method was used to interpolate between known elevations and areas. The original surface areas were taken from topography maps.
(SA)	Surface area (acre)	Surface area of reservoir based upon pool elevation. Measured by interpolating between graphically-measured surface areas at various pool elevations. The original surface areas were taken from topography maps.
(RR1)	Refill rate (acre-feet/day)	The rate in which the reservoir is rising or filling. Refill rate is based on change in surface area over time.
(RR2)	Refill rate (acre/day)	The rate in which the reservoir is rising or filling. Refill rate is based on change in pool content over time.
(PE)	Pool elevation (min., max., avg.) (ft)	The height of the pool's surface above mean sea level. Measured instantaneously with a gage.
(ΔPE)	Change in pool elevation (avg.) (ft/day)	The change in average daily pool elevation.
(IF)	Inflow (min., max., avg.) (cfs)	The amount of water flowing into the reservoir as determined by: inflow = outflow + change in reservoir storage.

Table 1. Continued.

	Variables	Description
(ΔIF)	Change in inflow (avg.) (cfs)	The difference in average daily inflow.
(1/IF)		The inverse of average daily inflow.
(OF)	Outflow (min., max., avg.) (cfs)	The discharge of water from the dam. Measured by a discharge gage below the dam. The gage is periodically checked with the hydraulic rating tables to obtain accurate instantaneous values.
(OF/IF)	Outflow/Inflow (avg.)	The proportion of outflow to inflow.
(OF-IF)	Outflow - Inflow (avg.) (cfs)	The difference between outflow and inflow.
(WPTT)	Water particle travel time (cfs)	The amount of time a water particle is assumed to take traveling from the release site to the dam. This is modeled by the Army Corps of Engineers for 3 pool elevations (1070, 1100, 1125 ft) and outflows from 200 to 1300 cfs.
(T)	Temperature (°C)	Stream temperature measured hourly by thermograph and daily average temperature calculated, or measured, once in the morning.
(IT)	Inflow turbidity (NTU)	Instantaneous turbidity measurement of the Green River at elevation 1160 ft (near release site). Measurements were taken weekday mornings.
(OT)	Outflow turbidity (NTU)	Turbidity measurement of the reservoir outflow at the dam. Measurements were taken weekday mornings.

Table 2. Pairwise linear correlations (r) between smolt travel time through the Howard Hanson Reservoir and potential predictor variables.

Variable	Correlation	Variable	Correlation
Outflow/Inflow	0.476*	Weight	0.208*
Release Group	0.461*	Average Inflow	0.207*
Refill Rate1	0.442*	Species	0.203*
Refill Rate2	0.442*	Pool Content	0.203*
Inflow-Outflow	0.424*	Minimum Inflow	0.184*
Inflow Turbidity	0.373*	Change in Inflow	0.164
Change in Pool Elevation	0.371*	Maximum Outflow	0.153
1/Average Inflow	0.342*	K-factor	0.151
Maximum Elevation	0.323*	Average Outflow	0.143
Average Elevation	0.316*	Stream Temperature	0.121
Minimum Elevation	0.310*	Minimum Outflow	0.110
Maximum Inflow	0.237*	ATPase	0.086
Surface Area	0.218*	Outflow Turbidity	0.072
Forklength	0.214*	Water Particle Travel Time	0.043

* Pairwise linear correlation is significant at the two-sided 0.05 level ($P_{Ho}(|r| \geq 0.167, n=138) = 0.05$).

Table 3. Summary of forward stepwise model selection for coho salmon and steelhead smolt travel times through Howard Hanson Reservoir without release group (RG) as a potential predictor. The model selected by the stepwise procedure is shaded.

(a) 1-variable models.

Rank	Variables	Deviance	R^2	AIC	C_p
1	OF/IF	82.83	0.23	248.49	81.97
2	RR1	85.25	0.19	255.75	89.18
3	RR2	85.32	0.20	255.96	88.47
4	OF-IF	85.95	0.18	257.86	89.33

(b) 2-variable models.

Rank	Variables	Deviance	R^2	AIC	C_p
1	OF/IF, WT	69.10	0.34	207.29	79.73
2	RR2, WT	69.50	0.36	208.49	80.93
3	RR1, WT	69.63	0.35	208.90	82.53
4	OF-IF, WT	70.64	0.33	211.93	83.51

(c) 3-variable models.

Rank	Variables	Deviance	R^2	AIC	C_p
1	OF/IF, WT, OT	60.14	0.47	180.41	69.65
*	RR2, WT, OT	67.46	0.39	202.38	79.19
*	RR1, WT, OT	67.42	0.39	202.27	79.81
*	RR2, WT, IT	68.09	0.39	204.26	76.19
*	RR1, WT, IT	67.91	0.38	203.75	77.71

* Models rank equally.

Table 4. Detailed regression results for selected models without release group as a predictor variable.

(a) Best 2-variable model without release group (RG) as a predictor variable.

Variable	Coefficient	Std. Error	P-value[1]	R^2
Constant	5.085	0.400	<0.001	
OF/IF	-3.687	0.456	<0.001	
WT	-0.0123	0.00224	<0.001	0.34

(b) Best 3-variable model without release group (RG) as a predictor variable.

Variable	Coefficient	Std. Error	P-value[1]	R^2
Constant	12.172	1.537	<0.001	
OF/IF	-4.654	0.433	<0.001	
WT	-0.0128	0.00214	<0.001	
OT	-6.422	1.426	<0.001	0.47

[1] Probability (2-tail) of observed coefficient estimate under the null hypothesis that the parameter is zero.

Table 5. Summary of forward stepwise model selection for coho salmon and steelhead smolt travel times through Howard Hanson Reservoir with release group (RG) as a potential predictor. The model selected by the stepwise procedure is shaded.

(a) 1-variable models.

Rank	Variables	Deviance	R^2	AIC	C_p
1	RG	79.31	0.21	237.92	92.54
2	RR	85.32	0.20	255.96	88.47

(b) 2-variable models.

Rank	Variables	Deviance	R^2	AIC	C_p
1	RG, IF (avg.)	22.28	0.82	66.84	21.56
2	RG, 1/IF	27.49	0.79	82.48	24.50
3	RG, WPTT	44.62	0.59	133.87	43.75
4	RG, PE (avg.)	54.17	0.51	162.50	54.15

(c) 3-variable models.

Rank	Variables	Deviance	R^2	AIC	C_p
1	RG, IF (avg.), ATP	18.84	0.84	56.51	19.33
2	RG, IF (avg.), FL	19.09	0.84	57.28	20.10
3	RG, IF (avg.), WT	19.39	0.84	58.18	20.15
4	RG, IF (avg.), SP	19.93	0.83	59.82	20.74

(d) 4-variable model.

Rank	Variables	Deviance	R^2	AIC	C_p
1	RG, IF (avg.), K, ATP	18.32	0.84	54.97	19.42

Table 6. Detailed regression results for selected models with release group as a predictor variable.

(a) Best 2-variable model with release group (RG) as a predictor variable.

Variable	Coefficient	Std. Error	*P*-value[1]	R^2
Constant	11.971	0.611	<0.001	
RG (low pool)	0			
RG (mid pool)	5.283	0.233	<0.001	
RG (high pool)	-2.875	0.200	<0.001	
IF (avg.)	-0.0134	0.000730	<0.001	0.82

(b) Best 3-variable model with release group (RG) as a predictor variable.

Variable	Coefficient	Std. Error	*P*-value[1]	R^2
Constant	12.131	0.567	<0.001	
RG (low pool)	0			
RG (mid pool)	5.27	0.211	<0.001	
RG (high pool)	-2.804	0.189	<0.001	
IF (avg.)	-0.0131	0.000677	<0.001	
ATP	-0.0266	0.00532	<0.001	0.84

(c) 4-variable model.

Variable	Coefficient	Std. Error	*P*-value[1]	R^2
Constant	11.521	0.644	<0.001	
RG (low pool)	0			
RG (mid pool)	5.318	0.211	<0.001	
RG (high pool)	-2.936	0.200	<0.001	
IF (avg.)	-0.0134	0.000692	<0.001	
K	0.811	0.400	0.04	
ATP	-0.0212	0.00586	<0.001	0.84

[1] Probability (2-tail) of observed coefficient estimate under the null hypothesis that the parameter is zero.

Appendix B. Release and recovery data for coho salmon and steelhead at low, mid, and full pools.

Fish number	Frequency (MHZ)	Pulse rate (ppm)	Date released	Time released	Travel time (days) from site A to		
					site M	site W	site Z
			Low pool				
			Coho salmon				
13	150.012	32-35	11-Apr	11:50	0.7	3.3	
14	150.103	32-35	11-Apr	11:50	0.4	1.5	
15	150.393	32-35	11-Apr	11:50	0.8	1.6	1.7
16	150.072	32-35	11-Apr	11:50			
17	150.423	32-35	11-Apr	11:50	0.4		
18	150.303	32-35	11-Apr	11:50	0.6	0.8	
19	150.042	32-35	11-Apr	11:50	7.4	7.6	19.5
20	150.332	32-35	11-Apr	11:50	0.7	1.5	
21	150.241	32-35	11-Apr	11:50	13.3		
22	150.273	32-35	11-Apr	11:50	0.6		
23	150.181	32-35	11-Apr	11:50	1.5	1.6	2.6
24	150.363	32-35	11-Apr	11:50	0.5		
37	150.483	32-35	12-Apr	11:30	1.5	5.8	
38	150.513	32-35	12-Apr	11:30		2.2	
39	150.542	32-35	12-Apr	11:30	1.5	2.2	11.3
40	150.573	32-35	12-Apr	11:30	0.7	2.2	
41	150.603	32-35	12-Apr	11:30	0.9	5.2	
42	150.632	32-35	12-Apr	11:30	0.6	0.7	1.7
43	150.662	32-35	12-Apr	11:30	2.6		
44	150.693	32-35	12-Apr	11:30			
45	150.722	32-35	12-Apr	11:30	2.6		
46	150.753	32-35	12-Apr	11:30			
47	150.783	32-35	12-Apr	11:30	0.7	2.2	
48 [A]	150.131	32-35	12-Apr	11:30			
61	150.812	32-35	13-Apr	11:00		4.2	
62	150.852	32-35	13-Apr	11:00	0.6	5.5	
63	150.891	32-35	13-Apr	11:00	1.6		
64	150.982	32-35	13-Apr	11:00			
65	151.012	32-35	13-Apr	11:00			
66	151.043	32-35	13-Apr	11:00	2.3		
67	151.102	32-35	13-Apr	11:00	1.4	2.2	
68	151.142	32-35	13-Apr	11:00		4.2	
69	151.172	32-35	13-Apr	11:00	1.5		
70	150.951	32-35	13-Apr	11:00	4.4	4.4	
71	150.212	32-35	13-Apr	11:00	0.6		
72	150.452	32-35	13-Apr	11:00	0.7	2.3	10.2
			Steelhead				
1	148.079	61	11-Apr	11:50	0.4	0.4	2.6

Appendix B. (continued)

Fish number	Frequency (MHZ)	Pulse rate (ppm)	Date released	Time released	Travel time (days) from site A to		
					site M	site W	site Z
2	148.086	61	11-Apr	11:50	1.4		
3	148.098	61	11-Apr	11:50	0.4	0.5	
4	148.128	61	11-Apr	11:50	0.4	1.4	
5	148.137	61	11-Apr	11:50	0.4	0.5	13.5
6	148.148	61	11-Apr	11:50	0.4	0.5	
7	148.158	61	11-Apr	11:50	1.4	1.8	
8	148.168	61	11-Apr	11:50			
9	148.177	61	11-Apr	11:50	0.2		
10	148.188	61	11-Apr	11:50	0.4	0.4	3.4
11	148.197	61	11-Apr	11:50		3.4	
12	148.208	61	11-Apr	11:50	0.3		
25	148.256	61	12-Apr	11:30			
26 [a]	148.308	61	12-Apr	11:30			
27	148.287	61	12-Apr	11:30	2.5		
28 [a]	148.298	61	12-Apr	11:30			
29	148.237	61	12-Apr	11:30	0.4		
30	148.266	61	12-Apr	11:30	1.4	2.6	
31	148.227	61	12-Apr	11:30	0.4	0.8	17.2
32	148.319	61	12-Apr	11:30	0.4		
33	148.327	61	12-Apr	11:30	0.7	2.2	
34	148.216	61	12-Apr	11:30		0.4	
35	148.108	61	12-Apr	11:30	0.5	0.7	
36	148.117	61	12-Apr	11:30			
49	148.447	61	13-Apr	11:00	0.4		
50	148.338	49	13-Apr	11:00	13.6	13.7	
51	148.366	61	13-Apr	11:00	0.3	4.2	
52	148.378	61	13-Apr	11:00	0.4		
53	148.387	61	13-Apr	11:00			
54	148.398	61	13-Apr	11:00	0.4		
55	148.416	61	13-Apr	11:00		1.3	11.6
56	148.426	61	13-Apr	11:00	0.5	4.2	
57	148.437	61	13-Apr	11:00	0.8	13.8	
58	148.277	61	13-Apr	11:00	0.4		
59	148.428	49	13-Apr	11:00		1.4	4.5
60	148.448	49	13-Apr	11:00			

Mid pool

Coho salmon

85	150.022	32-35	02-May	11:00		11.1	
86	150.052	32-35	02-May	11:00	1.7	13.2 MT	
87	150.113	32-35	02-May	11:00			
88	150.142	32-35	02-May	11:00			
89	150.192	32-35	02-May	11:00	1.7		

Appendix B. (continued)

Fish number	Frequency (MHZ)	Pulse rate (ppm)	Date released	Time released	Travel time (days) from site A to		
					site M	site W	site Z
90	150.252	32-35	02-May	11:00	7.0	10.2	
91	150.282	32-35	02-May	11:00	8.4		
92	150.312	32-35	02-May	11:00	1.8	7.5	
93	150.342	32-35	02-May	11:00	7.2	**14.2 MT**	
94 [a]	151.073	32-35	02-May	11:00			
95	150.372	32-35	02-May	11:00		8.0	
96	150.922	32-35	02-May	11:00			
109	150.223	32-35	03-May	11:30		11.7	
110	150.081	32-35	03-May	11:30	8.4		
111	150.402	32-35	03-May	11:30	7.7		
112	150.432	32-35	03-May	11:30		**13.2 MT**	
113	150.461	32-35	03-May	11:30			
114	150.493	32-35	03-May	11:30		6.3	
115	150.552	32-35	03-May	11:30	6.7		
116	150.582	32-35	03-May	11:30			
117	150.613	32-35	03-May	11:30		9.1	
118	150.642	32-35	03-May	11:30	6.9		
119	150.702	32-35	03-May	11:30			
120 [a]	150.731	32-35	03-May	11:30			
133	150.793	32-35	04-May	11:00			
134	150.831	32-35	04-May	11:00		**15.0 MT**	
135	150.869	32-35	04-May	11:00			
136	150.902	32-35	04-May	11:00		**11.2 MT**	
137	150.933	32-35	04-May	11:00			
138	150.962	32-35	04-May	11:00			
139	151.023	32-35	04-May	11:00		11.1	
140	151.052	32-35	04-May	11:00		**12.2 MT**	
141	151.082	32-35	04-May	11:00			
142	151.111	32-35	04-May	11:00			
143	150.672	32-35	04-May	11:00			
144	150.522	32-35	04-May	11:00			
			Steelhead				
73	148.248	61	02-May	11:00	7.1	9.0	
74	148.437	49	02-May	11:00	0.8	7.9	
75	148.418	49	02-May	11:00			
76	148.398	49	02-May	11:00		2.0	
77	148.388	49	02-May	11:00		7.1	
78	148.378	49	02-May	11:00			
79	148.368	49	02-May	11:00			
80	148.338	61	02-May	11:00	0.7	7.1	
81	148.317	49	02-May	11:00		**13.2 MT**	
82	148.308	49	02-May	11:00		2.0	
83	148.298	49	02-May	11:00		7.1	

Appendix B. (continued)

Fish number	Frequency (MHZ)	Pulse rate (ppm)	Date released	Time released	Travel time (days) from site A to site M	site W	site Z
84	148.288	49	02-May	11:00	7.1	**17.0** MT	
97	148.277	49	03-May	11:30			
98	148.328	49	03-May	11:30		6.0	
99	148.258	49	03-May	11:30			
100	148.268	49	03-May	11:30	6.1	6.1	
101	148.218	49	03-May	11:30	6.0	6.1	
102	148.208	49	03-May	11:30		0.9	
103	148.198	49	03-May	11:30		8.6	
104	148.187	49	03-May	11:30		9.2	
105	148.177	49	03-May	11:30		6.0	
106	148.167	49	03-May	11:30	6.0	6.9	
107	148.158	49	03-May	11:30	0.8	6.1	
108	148.148	49	03-May	11:30		7.0	
121	148.138	49	04-May	11:00	5.0	6.6	
122	148.128	49	04-May	11:00		5.1	
123	148.118	49	04-May	11:00			
124	148.108	49	04-May	11:00		5.1	
125	148.098	49	04-May	11:00			
126	148.086	49	04-May	11:00		5.1	
127	148.078	49	04-May	11:00	5.1		
128	148.446	41	04-May	11:00		**11.2** MT	
129	148.407	41	04-May	11:00		18.3	
130	148.398	41	04-May	11:00		7.8	
131	148.237	49	04-May	11:00			
132	148.228	49	04-May	11:00	5.0	5.9	

Full pool

Coho salmon

Fish number	Frequency (MHZ)	Pulse rate (ppm)	Date released	Time released	site M	site W	site Z
157	150.030	32-35	23-May	10:20	0.8	5.3	
158	150.062	32-35	23-May	10:20	0.8	2.0	
159	150.122	32-35	23-May	10:20	0.8	2.0	
160	150.151	32-35	23-May	10:20	0.8	5.3	
161	150.232	32-35	23-May	10:20	4.6	4.8	
162	150.261	32-35	23-May	10:20	2.8	4.2	
163	150.292	32-35	23-May	10:20	0.9	14.2	
164	150.322	32-35	23-May	10:20	0.8	2.0	
165	150.353	32-35	23-May	10:20	4.8	5.4	
166	150.382	32-35	23-May	10:20		5.9	
167	150.412	32-35	23-May	10:20	0.6	2.0	
168	150.442	32-35	23-May	10:20		5.0	
181	150.092	32-35	24-May	10:05	1.8	2.8	
182	150.200	32-35	24-May	10:05	0.7	**6.2** MT	
183	150.472	32-35	24-May	10:05	0.8	**6.2** MT	

Appendix B. (continued)

Fish number	Frequency (MHZ)	Pulse rate (ppm)	Date released	Time released	Travel time (days) from site A to site M	site W	site Z
184	150.503	32-35	24-May	10:05	0.8	10.3	
185	150.532	32-35	24-May	10:05	0.6	3.2	
186	150.562	32-35	24-May	10:05	2.2	13.6	
187	150.593	32-35	24-May	10:05	1.8	13.8	
188	150.623	32-35	24-May	10:05	1.2	6.2 MT	
189	150.652	32-35	24-May	10:05	0.9	13.4	
190	150.712	32-35	24-May	10:05			
191	150.743	32-35	24-May	10:05		1.1	
192	150.773	32-35	24-May	10:05		1.1	
203	150.682	32-35	25-May	10:25	3.6	5.2 MT	
204	150.803	32-35	25-May	10:25		8.2 MT	
205	150.842	32-35	25-May	10:25	18.8 D	20.0 D	
206	150.881	32-35	25-May	10:25			
207	150.913	32-35	25-May	10:25			
208	150.943	32-35	25-May	10:25			
209	151.003	32-35	25-May	10:25		5.2 MT	
210	151.033	32-35	25-May	10:25		5.2 MT	
211	151.062	32-35	25-May	10:25		8.4	
212	151.092	32-35	25-May	10:25	18.1		
213	151.131	32-35	25-May	10:25	19.2 D	20.9 D	
214	151.162	32-35	25-May	10:25	22.9 D	26.8 D	
215	151.192	32-35	25-May	10:25	18.3	19.2 D	
216	151.221	32-35	25-May	10:25	18.9 D	19.8 D	
			Steelhead				
145	148.077	41	23-May	10:20	0.9	1.1	
146	148.097	41	23-May	10:20	1.4	2.2	
147	148.108	41	23-May	10:20	2.7	3.1	
148	148.129	41	23-May	10:20	0.9	1.1	
149	148.138	41	23-May	10:20		1.1	
150	148.148	41	23-May	10:20	7.7	7.9	
151	148.157	41	23-May	10:20	5.8	5.9	
152	148.168	41	23-May	10:20	1.6	1.8	
153	148.177	41	23-May	10:20	0.9	1.0	
154	148.188	41	23-May	10:20	0.7	2.0	
155	148.197	41	23-May	10:20	0.8	2.2	
156	148.208	41	23-May	10:20			
169	148.118	41	24-May	10:05	2.8	4.0	
170	148.228	41	24-May	10:05	0.7	2.0	
171	148.237	41	24-May	10:05	0.9	2.8	
172	148.247	41	24-May	10:05	0.9	3.7	
173	148.259	41	24-May	10:05	1.1	2.3	
174	148.268	41	24-May	10:05	2.9	3.0	
175	148.278	41	24-May	10:05	0.9	1.2	

Appendix B. (continued)

Fish number	Frequency (MHZ)	Pulse rate (ppm)	Date released	Time released	Travel time (days) from site A to		
					site M	site W	site Z
176	148.287	41	24-May	10:05	0.9	1.2	
177	148.298	41	24-May	10:05	2.4	3.4	
178	148.307	41	24-May	10:05	0.7	1.2	
179	148.319	41	24-May	10:05	0.6	0.8	
180	148.328	41	24-May	10:05	0.9	3.0	
193	148.338	41	25-May	10:25	0.9	1.1	
194	148.368	41	25-May	10:25	1.2	1.7	
195	148.377	41	25-May	10:25	1.3	1.4	
196	148.089	41	25-May	10:25	0.8	1.0	
197	148.417	41	25-May	10:25			
198	148.426	41	25-May	10:25	0.7	3.7	
199 [A]	148.437	41	25-May	10:25			
200 [B]	148.247	49	25-May	10:25	10.2	12.0	
201	148.407	49	25-May	10:25	1.6	1.7	
202	148.217	41	25-May	10:25	3.7		

[A] Tag recovered along shoreline near its release site, possibly a result of predation.

[B] Tag recovered along shoreline near release site after its detection at site W.

MT Travel time based on manual tracking detection.

D Deleted from travel time analysis because detection occurred after the standard monitoring period.

Appendix C. Morphological, physiological and class variables used in the GLM analysis.

Fish number	Species[A] (SP)[B]	Fork length (mm) (FL)	Weight (g) (WT)	Fulton K factor (K)	Mean ATPase (surrogate) (ATP)	Pool treatment (RG)	Travel time to site W (days) (TT)
1	WST	200	87.0	1.09	17.8	Low	0.44
2	WST	171	55.1	1.10	17.8	Low	0
3	WST	185	64.6	1.02	17.8	Low	0.48
4	WST	193	76.4	1.06	17.8	Low	1.43
5	WST	203	78.6	0.94	17.8	Low	0.51
6	WST	191	71.9	1.03	17.8	Low	0.48
7	WST	203	91.2	1.09	17.8	Low	1.84
8	WST	190	67.6	0.99	17.8	Low	0
9	WST	174	55.5	1.05	17.8	Low	0
10	WST	193	73.5	1.02	17.8	Low	0.43
11	WST	192	72.9	1.03	17.8	Low	3.36
12	WST	194	75.6	1.04	17.8	Low	0
13	COS	135	26.0	1.06	14.2	Low	3.32
14	COS	142	28.5	1.00	14.2	Low	1.52
15	COS	130	24.9	1.13	14.2	Low	1.64
16	COS	132	23.3	1.01	14.2	Low	0
17	COS	164	44.6	1.01	14.2	Low	0
18	COS	132	23.8	1.03	14.2	Low	0.82
19	COS	135	25.8	1.05	14.2	Low	7.61
20	COS	130	24.6	1.12	14.2	Low	1.47
21	COS	147	34.0	1.07	14.2	Low	0
22	COS	175	55.3	1.03	14.2	Low	0
23	COS	147	34.2	1.08	14.2	Low	1.64
24	COS	150	36.7	1.09	14.2	Low	0
25	WST	190	66.1	0.96	16.9	Low	0
26	WST	180	54.8	0.94	16.9	Low	0
27	WST	189	59.1	0.88	16.9	Low	0
28	WST	185	62.9	0.99	16.9	Low	0
29	WST	190	68.7	1.00	16.9	Low	0
30	WST	198	81.5	1.05	16.9	Low	2.60
31	WST	214	97.0	0.99	16.9	Low	0.77
32	WST	197	69.3	0.91	16.9	Low	0
33	WST	182	61.3	1.02	16.9	Low	2.20
34	WST	189	71.2	1.05	16.9	Low	0.42
35	WST	204	86.4	1.02	16.9	Low	0.68
36	WST	201	82.5	1.02	16.9	Low	0
37	COS	134	23.3	0.97	14.2	Low	5.80
38	COS	143	31.3	1.07	14.2	Low	2.20
39	COS	134	25.2	1.05	14.2	Low	2.21
40	COS	130	24.6	1.12	14.2	Low	2.21
41	COS	140	29.1	1.06	14.2	Low	5.20
42	COS	132	26.5	1.15	14.2	Low	0.73
43	COS	142	28.8	1.01	14.2	Low	0
44	COS	132	25.5	1.11	14.2	Low	0

Appendix C. (continued)

Fish number	Species	Fork length (mm)	Weight (g)	Fulton K factor	Mean ATPase (surrogate)	Pool treatment (release group)	Travel time to site W (days)
45	COS	136	27.2	1.08	14.2	Low	0.00
46	COS	134	24.8	1.03	14.2	Low	0.00
47	COS	146	31.5	1.01	14.2	Low	2.20
48	COS	136	25.9	1.03	14.2	Low	0.00
49	WST	175	53.7	1.00	23.2	Low	0.00
50	WST	170	49.5	1.01	23.2	Low	13.72
51	WST	198	80.5	1.04	23.2	Low	4.22
52	WST	200	76.4	0.96	23.2	Low	0.00
53	WST	200	76.4	0.96	23.2	Low	0.00
54	WST	207	86.3	0.97	23.2	Low	0.00
55	WST	194	77.5	1.06	23.2	Low	1.26
56	WST	196	76.8	1.02	23.2	Low	4.22
57	WST	185	58.0	0.92	23.2	Low	13.76
58	WST	212	81.7	0.86	23.2	Low	0.00
59	WST	188	64.3	0.97	23.2	Low	1.40
60	WST	199	73.0	0.93	23.2	Low	0.00
61	COS	130	22.7	1.03	15.5	Low	4.22
62	COS	160	32.0	0.78	15.5	Low	5.53
63	COS	135	21.5	0.87	15.5	Low	0.00
64	COS	142	27.7	0.97	15.5	Low	0.00
65	COS	142	23.0	0.80	15.5	Low	0.00
66	COS	140	21.6	0.79	15.5	Low	0.00
67	COS	161	31.0	0.74	15.5	Low	2.23
68	COS	144	23.4	0.78	15.5	Low	4.22
69	COS	144	24.7	0.83	15.5	Low	0.00
70	COS	148	25.0	0.77	15.5	Low	4.40
71	COS	152	28.5	0.81	15.5	Low	0.00
72	COS	148	26.2	0.81	15.5	Low	2.27
73	WST	197	77.7	1.02	21.0	Mid	8.98
74	WST	211	107.9	1.15	21.0	Mid	7.92
75	WST	203	85.7	1.02	21.0	Mid	0.00
76	WST	225	109.5	0.96	21.0	Mid	1.98
77	WST	178	67.1	1.19	21.0	Mid	7.06
78	WST	197	79.6	1.04	21.0	Mid	0.00
79	WST	204	82.1	0.97	21.0	Mid	0.00
80	WST	191	77.9	1.12	21.0	Mid	7.08
81	WST	219	108.2	1.03	21.0	Mid	13.17
82	WST	200	82.4	1.03	21.0	Mid	1.97
83	WST	205	99.6	1.16	21.0	Mid	7.08
84	WST	203	89.0	1.06	21.0	Mid	17.00
85	COS	148	40.2	1.24	14.3	Mid	11.10
86	COS	142	31.5	1.10	14.3	Mid	13.18
87	COS	136	28.3	1.13	14.3	Mid	0.00
88	COS	131	27.6	1.23	14.3	Mid	0.00

Appendix C. (continued)

Fish number	Species	Fork length (mm)	Weight (g)	Fulton K factor	Mean ATPase (surrogate)	Pool treatment (release group)	Travel time to site W (days)
89	COS	135	29.5	1.20	14.3	Mid	0.00
90	COS	136	29.1	1.16	14.3	Mid	10.25
91	COS	164	49.9	1.13	14.3	Mid	0.00
92	COS	150	38.7	1.15	14.3	Mid	7.47
93	COS	133	24.8	1.05	14.3	Mid	14.18
94	COS	139	31.4	1.17	14.3	Mid	0.00
95	COS	132	28.9	1.26	14.3	Mid	8.04
96	COS	134	24.6	1.02	14.3	Mid	0.00
97	WST	207	83.3	0.94	20.1	Mid	0.00
98	WST	206	85.2	0.97	20.1	Mid	6.04
99	WST	236	131.7	1.00	20.1	Mid	0.00
100	WST	205	94.6	1.10	20.1	Mid	6.12
101	WST	187	68.5	1.05	20.1	Mid	6.15
102	WST	209	81.7	0.90	20.1	Mid	0.90
103	WST	197	70.2	0.92	20.1	Mid	8.55
104	WST	186	66.7	1.04	20.1	Mid	9.21
105	WST	182	63.4	1.05	20.1	Mid	6.04
106	WST	220	97.9	0.92	20.1	Mid	6.94
107	WST	207	93.2	1.05	20.1	Mid	6.10
108	WST	210	95.8	1.03	20.1	Mid	6.99
109	COS	151	39.8	1.16	13.1	Mid	11.70
110	COS	135	27.0	1.10	13.1	Mid	0.00
111	COS	139	31.3	1.16	13.1	Mid	0.00
112	COS	139	30.9	1.15	13.1	Mid	13.16
113	COS	134	29.0	1.20	13.1	Mid	0.00
114	COS	139	31.9	1.19	13.1	Mid	6.31
115	COS	139	35.5	1.32	13.1	Mid	0.00
116	COS	139	29.9	1.11	13.1	Mid	0.00
117	COS	144	33.1	1.11	13.1	Mid	9.05
118	COS	130	25.6	1.17	13.1	Mid	0.00
119	COS	140	30.9	1.13	13.1	Mid	0.00
120	COS	130	25.0	1.14	13.1	Mid	0.00
121	WST	195	78.7	1.06	30.3	Mid	6.59
122	WST	188	65.7	0.99	30.3	Mid	5.07
123	WST	173	48.2	0.93	30.3	Mid	0.00
124	WST	185	62.2	0.98	30.3	Mid	5.13
125	WST	210	85.6	0.92	30.3	Mid	0.00
126	WST	206	86.4	0.99	30.3	Mid	5.13
127	WST	173	52.0	1.00	30.3	Mid	0.00
128	WST	206	82.3	0.94	30.3	Mid	11.18
129	WST	195	72.8	0.98	30.3	Mid	18.28
130	WST	191	71.1	1.02	30.3	Mid	7.81
131	WST	191	70.8	1.02	30.3	Mid	0.00
132	WST	203	85.3	1.02	30.3	Mid	5.92

Appendix C. (continued)

Fish number	Species	Fork length (mm)	Weight (g)	Fulton K factor	Mean ATPase (surrogate)	Pool treatment (release group)	Travel time to site W (days)
133	COS	139	28.2	1.05	15.1	Mid	0.00
134	COS	137	28.1	1.09	15.1	Mid	15.01
135	COS	143	25.5	0.87	15.1	Mid	0.00
136	COS	137	29.2	1.14	15.1	Mid	11.18
137	COS	132	26.0	1.13	15.1	Mid	0.00
138	COS	130	25.4	1.16	15.1	Mid	0.00
139	COS	149	35.8	1.08	15.1	Mid	11.08
140	COS	139	33.0	1.23	15.1	Mid	12.18
141	COS	135	27.9	1.13	15.1	Mid	0.00
142	COS	132	26.8	1.17	15.1	Mid	0.00
143	COS	138	31.3	1.19	15.1	Mid	0.00
144	COS	137	30.4	1.18	15.1	Mid	0.00
145	WST	190	79.2	1.15	23.4	Full	1.06
146	WST	187	72.0	1.10	23.4	Full	2.20
147	WST	202	81.7	0.99	23.4	Full	3.09
148	WST	195	83.5	1.13	23.4	Full	1.11
149	WST	209	98.3	1.08	23.4	Full	1.10
150	WST	178	58.6	1.04	23.4	Full	7.93
151	WST	200	76.4	0.95	23.4	Full	5.91
152	WST	187	70.8	1.08	23.4	Full	1.85
153	WST	208	101.1	1.12	23.4	Full	1.05
154	WST	198	82.4	1.06	23.4	Full	2.04
155	WST	197	76.2	1.00	23.4	Full	2.19
156	WST	199	86.5	1.10	23.4	Full	0.00
157	COS	132	25.7	1.12	8.8	Full	5.27
158	COS	132	27.1	1.18	8.8	Full	1.99
159	COS	136	33.1	1.31	8.8	Full	1.99
160	COS	142	29.6	1.03	8.8	Full	5.35
161	COS	137	29.7	1.16	8.8	Full	4.84
162	COS	133	27.5	1.17	8.8	Full	4.18
163	COS	135	27.1	1.10	8.8	Full	14.21
164	COS	130	21.4	0.97	8.8	Full	1.99
165	COS	132	27.0	1.17	8.8	Full	5.37
166	COS	133	26.5	1.13	8.8	Full	5.89
167	COS	135	26.9	1.09	8.8	Full	1.99
168	COS	133	26.7	1.14	8.8	Full	5.05
169	WST	191	64.4	0.92	24.0	Full	3.97
170	WST	183	59.1	0.96	24.0	Full	1.97
171	WST	206	82.5	0.94	24.0	Full	2.77
172	WST	191	71.6	1.03	24.0	Full	3.71
173	WST	179	61.9	1.08	24.0	Full	2.33
174	WST	205	91.3	1.06	24.0	Full	2.95
175	WST	202	85.7	1.04	24.0	Full	1.21
176	WST	221	114.0	1.06	24.0	Full	1.22

Appendix C. (continued)

Fish number	Species	Fork length (mm)	Weight (g)	Fulton K factor	Mean ATPase (surrogate)	Pool treatment (release group)	Travel time to site W (days)
177	WST	187	64.5	0.99	24.0	Full	3.39
178	WST	203	79.5	0.95	24.0	Full	1.20
179	WST	174	53.6	1.02	24.0	Full	0.79
180	WST	176	58.3	1.07	24.0	Full	2.99
181	COS	134	24.9	1.03	9.0	Full	2.84
182	COS	133	25.6	1.09	9.0	Full	6.20
183	COS	134	27.6	1.15	9.0	Full	6.20
184	COS	133	25.4	1.08	9.0	Full	10.34
185	COS	134	26.3	1.09	9.0	Full	3.23
186	COS	132	22.6	0.98	9.0	Full	13.59
187	COS	132	26.2	1.14	9.0	Full	13.78
188	COS	138	30.0	1.14	9.0	Full	6.20
189	COS	138	27.8	1.06	9.0	Full	13.36
190	COS	133	25.8	1.10	9.0	Full	0.00
191	COS	132	24.6	1.07	9.0	Full	1.07
192	COS	134	24.3	1.01	9.0	Full	1.08
193	WST	224	113.3	1.01	25.7	Full	1.05
194	WST	209	88.0	0.96	25.7	Full	1.72
195	WST	223	93.5	0.84	25.7	Full	1.36
196	WST	189	71.5	1.06	25.7	Full	0.99
197	WST	191	77.1	1.11	25.7	Full	0.00
198	WST	200	84.6	1.06	25.7	Full	3.68
199	WST	179	56.5	0.98	25.7	Full	0.00
200	WST	182	57.9	0.96	25.7	Full	11.97
201	WST	199	81.4	1.03	25.7	Full	1.71
202	WST	176	54.7	1.00	25.7	Full	0.00
203	COS	140	26.9	0.98	9.5	Full	5.19
204	COS	136	27.6	1.10	9.5	Full	8.16
205	COS	143	31.4	1.07	9.5	Full	0.00
206	COS	137	28.5	1.11	9.5	Full	0.00
207	COS	136	27.5	1.09	9.5	Full	0.00
208	COS	134	26.2	1.09	9.5	Full	0.00
209	COS	140	29.7	1.08	9.5	Full	5.19
210	COS	138	29.6	1.13	9.5	Full	5.19
211	COS	130	24.0	1.09	9.5	Full	8.35
212	COS	135	26.6	1.08	9.5	Full	0.00
213	COS	137	29.2	1.13	9.5	Full	0.00
214	COS	133	24.7	1.05	9.5	Full	0.00
215	COS	135	24.6	1.00	9.5	Full	0.00
216	COS	137	26.9	1.05	9.5	Full	0.00

[A] WST (steelhead)
COS (coho salmon)
[B] GLM acronyms

Appendix D. Environmental variables used in the GLM analysis. Each measurement is the average of the environmental condition during a fish's travel time.

Fish no.	Surface area (acre) (SA)[a]	Refill rate1 (acre/day) (RR1)	Refill rate2 (acre-ft/day) (RR2)	Pool Elevation (ft) min. (PE)	avg. (PE)	max (PE)	Δ (PE)	Inflow (cfs) min. (IF)	avg. (IF)	max. (IF)
1	128.50	102.0	2.60	1076.74	1077.50	1077.97	0.00	867.0	923.1	978.0
3	128.50	102.0	2.60	1076.74	1077.50	1077.97	0.00	867.0	923.1	978.0
4	129.80	65.0	1.95	1077.37	1077.80	1078.06	0.30	845.5	892.0	931.0
5	129.80	65.0	1.95	1077.37	1077.80	1078.06	0.00	845.5	892.0	931.0
6	128.50	102.0	2.60	1076.74	1077.50	1077.97	0.30	867.0	923.1	978.0
7	130.67	44.3	1.30	1077.63	1077.99	1078.20	0.49	840.0	885.2	927.7
10	128.50	102.0	2.60	1076.74	1077.50	1077.97	0.49	867.0	923.1	978.0
11	131.10	55.0	1.65	1077.78	1078.09	1078.33	0.59	822.3	865.7	904.8
13	131.10	55.0	1.65	1077.78	1078.09	1078.33	0.00	822.3	865.7	904.8
14	130.67	44.3	1.30	1077.63	1077.99	1078.20	0.10	840.0	885.2	927.7
15	130.67	44.3	1.30	1077.63	1077.99	1078.20	0.00	840.0	885.2	927.7
18	129.80	65.0	1.95	1077.37	1077.80	1078.06	0.19	845.5	892.0	931.0
19	135.26	74.9	2.49	1078.65	1079.02	1079.33	1.22	728.9	766.1	802.3
20	129.80	65.0	1.95	1077.37	1077.80	1078.06	1.22	845.5	892.0	931.0
23	130.67	44.3	1.30	1077.63	1077.99	1078.20	0.19	840.0	885.2	927.7
30	132.75	34.3	1.00	1078.28	1078.47	1078.62	0.48	785.0	822.1	858.0
31	131.75	15.5	0.65	1078.07	1078.23	1078.32	0.24	826.5	866.2	902.5
33	131.97	39.3	1.33	1078.12	1078.29	1078.45	0.06	807.3	846.5	880.3
34	131.10	28.0	1.30	1077.99	1078.09	1078.15	0.20	824.0	860.9	884.0
35	131.75	15.5	0.65	1078.07	1078.23	1078.32	0.14	826.5	866.2	902.5
37	134.56	66.4	2.26	1078.57	1078.87	1079.16	0.64	727.3	763.1	797.1
38	131.97	39.3	1.33	1078.12	1078.29	1078.45	0.58	807.3	846.5	880.3
39	131.97	39.3	1.33	1078.12	1078.29	1078.45	0.00	807.3	846.5	880.3
40	131.97	39.3	1.33	1078.12	1078.29	1078.45	0.00	807.3	846.5	880.3
41	133.38	47.2	1.75	1078.40	1078.62	1078.85	0.33	744.7	779.2	811.5
42	131.75	15.5	0.65	1078.07	1078.23	1078.32	0.39	826.5	866.2	902.5
47	131.97	39.3	1.33	1078.12	1078.29	1078.45	0.06	807.3	846.5	880.3
50	154.79	193.6	6.09	1082.39	1082.94	1083.48	4.65	674.1	706.8	741.2
51	133.84	51.0	1.84	1078.48	1078.73	1078.99	4.21	728.8	762.9	797.0
55	132.40	45.0	1.35	1078.18	1078.39	1078.60	0.34	799.0	839.4	878.5
56	133.84	51.0	1.84	1078.48	1078.73	1078.99	0.34	728.8	762.9	797.0
57	154.79	193.6	6.09	1082.39	1082.94	1083.48	4.21	674.1	706.8	741.2
59	132.40	45.0	1.35	1078.18	1078.39	1078.60	4.55	799.0	839.4	878.5
61	133.84	51.0	1.84	1078.48	1078.73	1078.99	0.34	728.8	762.9	797.0
62	135.13	72.8	2.42	1078.67	1079.00	1079.33	0.27	711.2	746.9	782.7
67	133.30	36.3	0.90	1078.37	1078.60	1078.77	0.40	772.0	809.1	849.3
68	133.84	51.0	1.84	1078.48	1078.73	1078.99	0.13	728.8	762.9	797.0
70	133.84	51.0	1.84	1078.48	1078.73	1078.99	0.00	728.8	762.9	797.0
72	133.30	36.3	0.90	1078.37	1078.60	1078.77	0.13	772.0	809.1	849.3
73	417.49	947.6	24.07	1116.70	1117.84	1118.96	39.24	1069.5	1153.8	1228.8
74	406.28	955.8	24.56	1115.67	1116.84	1117.99	1.00	1063.7	1148.8	1227.2
82	330.70	1200.7	32.10	1107.68	1109.32	1110.99	11.98	1059.3	1184.9	1294.7
83	395.28	954.6	24.61	1114.62	1115.82	1117.00	6.50	1052.9	1139.9	1219.8
84	494.86	770.8	19.8	1123.25	1124.10	1124.92	8.28	963.2	1063.8	1173.4

Appendix D. (continued)

Fish no.	Surface area (acre) (SA)[a]	Refill rate1 (acre/day) (RR1)	Refill rate2 (acre-ft/day) (RR2)	Pool Elevation (ft) min. (PE)	avg. (PE)	max (PE)	Δ (PE)	Inflow (cfs) min. (IF)	avg. (IF)	max. (IF)
85	438.96	886.0	22.4	1118.65	1119.70	1120.72	4.40	1045.4	1132.3	1214.4
86	458.13	839.6	21.5	1120.34	1121.30	1122.23	1.60	1020.7	1107.1	1186.3
90	428.45	921.8	23.4	1117.70	1118.81	1119.87	2.49	1058.9	1147.0	1225.0
92	395.28	954.6	24.6	1114.62	1115.82	1117.00	2.99	1052.9	1139.9	1219.8
93	467.45	829.9	21.3	1121.10	1122.04	1122.95	6.22	1001.8	1101.8	1220.1
95	406.28	955.8	24.6	1115.67	1116.84	1117.99	5.20	1063.7	1148.8	1227.2
98	409.26	921.4	23.4	1116.12	1117.29	1118.39	0.45	1082.1	1150.4	1217.0
100	409.26	921.4	23.4	1116.12	1117.29	1118.39	0.00	1082.1	1150.4	1217.0
101	409.26	921.4	23.4	1116.12	1117.29	1118.39	0.00	1082.1	1150.4	1217.0
102	347.35	1207.5	31.8	1109.44	1111.19	1112.85	6.10	1165.0	1244.2	1322.5
103	441.56	895.3	22.4	1119.06	1120.13	1121.13	8.94	1080.0	1155.0	1223.6
104	441.56	895.3	22.4	1119.06	1120.13	1121.13	0.00	1080.0	1155.0	1223.6
105	409.26	921.4	23.4	1116.12	1117.29	1118.39	2.84	1082.1	1150.4	1217.0
106	419.89	926.9	23.5	1117.11	1118.25	1119.33	0.96	1090.6	1159.1	1225.8
107	409.26	921.4	23.4	1116.12	1117.29	1118.39	0.96	1082.1	1150.4	1217.0
108	419.89	926.9	23.5	1117.11	1118.25	1119.33	0.96	1090.6	1159.1	1225.8
109	470.49	812.9	20.6	1121.58	1122.51	1123.38	4.26	1034.0	1110.2	1182.2
112	479.60	804.4	20.4	1122.31	1123.21	1124.07	0.70	1012.8	1104.3	1218.7
114	409.26	921.4	23.4	1116.12	1117.29	1118.39	5.92	1082.1	1150.4	1217.0
117	441.56	895.3	22.4	1119.06	1120.13	1121.13	2.84	1080.0	1155.0	1223.6
121	443.41	876.8	21.7	1119.42	1120.43	1121.38	0.30	1081.0	1149.6	1214.6
122	422.43	862.5	21.6	1117.56	1118.60	1119.57	1.83	1062.7	1129.6	1197.8
124	422.43	862.5	21.6	1117.56	1118.60	1119.57	0.00	1062.7	1129.6	1197.8
126	422.43	862.5	21.6	1117.56	1118.60	1119.57	0.00	1062.7	1129.6	1197.8
128	482.18	774.3	19.5	1122.76	1123.60	1124.39	5.00	1020.3	1096.5	1169.8
129	539.92	638.2	16.2	1127.07	1127.73	1128.34	4.13	900.9	994.8	1095.5
130	453.93	853.1	21.1	1120.35	1121.32	1122.23	6.41	1066.8	1141.7	1211.6
132	432.70	877.1	22.0	1118.48	1119.51	1120.48	1.81	1075.1	1142.6	1210.6
134	517.49	713.3	18.0	1125.43	1126.17	1126.87	6.66	955.6	1050.4	1159.4
136	482.18	774.3	19.5	1122.76	1123.60	1124.39	2.57	1020.3	1096.5	1169.8
139	482.18	774.3	19.5	1122.76	1123.60	1124.39	0.00	1020.3	1096.5	1169.8
140	491.09	768.2	19.4	1123.45	1124.28	1125.05	0.68	998.5	1091.2	1210.0
145	676.70	261.0	7.5	1136.72	1136.91	1137.09	12.63	583.0	650.4	715.5
146	680.47	274.0	7.5	1136.91	1137.10	1137.29	0.19	561.3	632.7	702.0
147	684.23	272.5	7.6	1137.11	1137.30	1137.49	0.20	550.5	617.2	680.3
148	676.70	261.0	7.5	1136.72	1136.91	1137.09	0.39	583.0	650.4	715.5
149	676.70	261.0	7.5	1136.72	1136.91	1137.09	0.00	583.0	650.4	715.5
150	700.68	222.0	6.0	1137.99	1138.15	1138.30	1.24	487.3	562.8	638.9
151	694.90	239.6	6.6	1137.68	1137.85	1138.02	0.30	512.3	583.6	650.4
152	680.47	274.0	7.5	1136.91	1137.10	1137.29	0.75	561.3	632.7	702.0
153	676.70	261.0	7.5	1136.72	1136.91	1137.09	0.19	583.0	650.4	715.5
154	680.47	274.0	7.5	1136.91	1137.10	1137.29	0.19	561.3	632.7	702.0
155	680.47	274.0	7.5	1136.91	1137.10	1137.29	0.00	561.3	632.7	702.0
157	691.55	253.0	7.0	1137.50	1137.68	1137.86	0.58	525.5	594.2	658.5
158	680.47	274.0	7.5	1136.91	1137.10	1137.29	0.58	561.3	632.7	702.0
159	680.47	274.0	7.5	1136.91	1137.10	1137.29	0.00	561.3	632.7	702.0

Appendix D. (continued)

Fish no.	Surface area (acre) (SA)[A]	Refill rate1 (acre/ day) (RR1)	Refill rate2 (acre-ft/day) (RR2)	Pool Elevation (ft) min. (PE)	avg. (PE)	max (PE)	Δ (PE)	Inflow (cfs) min. (IF)	avg. (IF)	max. (IF)
160	691.55	253.0	7.0	1137.50	1137.68	1137.86	0.58	525.5	594.2	658.0
161	691.55	253.0	7.0	1137.50	1137.68	1137.86	0.00	525.5	594.2	658.5
162	688.04	265.0	7.2	1137.31	1137.50	1137.68	0.18	544.0	605.6	667.2
163	715.06	210.1	5.8	1138.75	1138.89	1139.03	1.39	430.7	509.9	597.4
164	680.47	274.0	7.5	1136.91	1137.10	1137.29	1.79	561.3	632.7	702.0
165	691.55	253.0	7.0	1137.50	1137.68	1137.86	0.58	525.5	594.2	658.5
166	694.90	239.6	6.6	1137.68	1137.85	1138.02	0.17	512.3	583.6	650.4
167	680.47	274.0	7.5	1136.91	1137.10	1137.29	0.75	561.3	632.7	702.0
168	691.55	253.0	7.0	1137.50	1137.68	1137.86	0.58	525.5	594.2	658.5
169	695.26	253.0	6.9	1137.70	1137.87	1138.05	0.19	510.6	581.1	651.0
170	687.97	279.0	7.6	1137.31	1137.50	1137.69	0.37	534.0	602.9	675.0
171	691.80	268.0	7.2	1137.51	1137.69	1137.88	0.19	530.0	592.0	660.0
172	695.26	253.0	6.9	1137.70	1137.87	1138.05	0.18	510.6	581.1	651.0
173	687.97	279.0	7.6	1137.31	1137.50	1137.69	0.37	534.0	602.9	675.0
174	691.80	268.0	7.2	1137.51	1137.69	1137.88	0.19	530.0	592.0	660.0
175	684.20	284.5	7.6	1137.11	1137.29	1137.49	0.40	542.0	619.1	705.0
176	684.20	284.5	7.6	1137.11	1137.29	1137.49	0.00	542.0	619.1	705.0
177	691.80	268.0	7.2	1137.51	1137.69	1137.88	0.40	530.0	592.0	660.0
178	684.20	284.5	7.6	1137.11	1137.29	1137.49	0.40	542.0	619.1	705.0
179	684.20	284.5	7.6	1137.11	1137.29	1137.49	0.00	542.0	619.1	705.0
180	691.80	268.0	7.2	1137.51	1137.69	1137.88	0.40	530.0	592.0	660.0
181	691.80	268.0	7.2	1137.51	1137.69	1137.88	0.00	530.0	592.0	660.0
182	701.46	229.4	6.1	1138.03	1138.19	1138.35	0.50	483.7	561.0	638.9
183	701.46	229.4	6.1	1138.03	1138.19	1138.35	0.00	483.7	561.0	638.9
184	711.07	193.6	5.1	1138.56	1138.69	1138.83	0.50	438.0	515.1	597.3
185	691.80	268.0	7.2	1137.51	1137.69	1137.88	1.00	530.0	592.0	660.0
186	720.83	202.4	5.4	1139.04	1139.18	1139.32	1.49	411.9	494.1	585.2
187	720.83	202.4	5.4	1139.04	1139.18	1139.32	0.00	411.9	494.1	585.2
188	701.46	229.4	6.1	1138.03	1138.19	1138.35	0.99	483.7	561.0	638.9
189	718.06	207.0	5.7	1138.91	1139.05	1139.18	0.86	418.6	499.1	590.4
191	684.20	284.5	7.6	1137.11	1137.29	1137.49	1.76	542.0	619.1	705.0
192	684.20	284.5	7.6	1137.11	1137.29	1137.49	0.00	542.0	619.1	705.0
193	691.75	284.0	7.7	1137.50	1137.70	1137.89	0.41	518.0	584.0	645.0
194	695.60	267.7	7.0	1137.70	1137.89	1138.08	0.19	518.0	575.7	635.0
195	691.75	284.0	7.7	1137.50	1137.70	1137.89	0.19	518.0	584.0	645.0
196	691.75	284.0	7.7	1137.50	1137.70	1137.89	0.00	518.0	584.0	645.0
198	702.18	231.0	6.2	1138.06	1138.23	1138.39	0.53	484.0	556.9	624.4
200	720.96	202.2	5.5	1139.06	1139.20	1139.33	0.97	407.2	488.2	579.2
201	695.60	267.7	7.0	1137.70	1137.89	1138.08	1.31	518.0	575.7	635.0
203	704.97	222.8	5.8	1138.21	1138.37	1138.52	0.48	470.0	547.7	622.8
204	712.06	191.1	5.0	1138.61	1138.74	1138.87	0.37	437.0	514.3	592.7
209	704.97	222.8	5.8	1138.21	1138.37	1138.52	0.37	470.0	547.7	622.8
210	704.97	222.8	5.8	1138.21	1138.37	1138.52	0.00	470.0	547.7	622.8
211	712.06	191.1	5.0	1138.61	1138.74	1138.87	0.37	437.0	514.3	592.7

Appendix D. (continued)

Fish no.	Outflow (cfs) min. (OF)	avg. (OF)	max. (OF)	Ratio of outflow to inflow (OF/IF)	Outflow - Inflow (cfs) (OF-IF)	Temp-erature (·C) (T)	Inflow turbid-ity (NTU) (IT)	Outflow turbid-ity (NTU) (OY)	Water particle travel time (s/ft) (WPTT)	Pool content (acre-ft) (C)
1	833.0	839.5	843.0	0.91	83.6	6.32	1.31	1.00	35.7	2056.0
3	833.0	839.5	843.0	0.91	83.6	6.32	1.31	1.00	35.7	2056.0
4	838.0	843.6	845.5	0.95	48.4	5.89	1.10	0.95	35.5	2107.0
5	838.0	843.6	845.5	0.95	48.4	5.89	1.10	0.95	35.5	2107.0
6	833.0	839.5	843.0	0.91	83.6	6.32	1.31	1.00	35.7	2056.0
7	841.3	846.1	848.0	0.96	39.1	5.96	1.10	0.97	37.4	2133.3
10	833.0	839.5	843.0	0.91	83.6	6.32	1.31	1.00	35.7	2056.0
11	811.3	831.8	849.3	0.96	33.9	5.84	1.16	0.97	37.8	2147.3
13	811.3	831.8	849.3	0.96	33.9	5.84	1.16	0.97	37.8	2147.3
14	841.3	846.1	848.0	0.96	39.1	5.96	1.10	0.97	37.4	2133.3
15	841.3	846.1	848.0	0.96	39.1	5.96	1.10	0.97	37.4	2133.3
18	838.0	843.6	845.5	0.95	48.4	5.89	1.10	0.95	35.5	2107.0
19	706.6	726.2	745.7	0.95	39.9	5.91	1.05	0.91	45.8	2271.4
20	838.0	843.6	845.5	0.95	48.4	5.89	1.10	0.95	35.5	2107.0
23	841.3	846.1	848.0	0.96	39.1	5.96	1.10	0.97	37.4	2133.3
30	784.5	804.1	821.0	0.98	18.0	5.72	1.13	0.95	38.7	2202.3
31	845.5	849.4	850.5	0.98	16.9	5.78	1.00	0.95	37.1	2172.0
33	804.0	829.2	851.3	0.98	17.3	5.68	1.10	0.97	37.8	2177.7
34	843.0	847.8	848.0	0.98	13.1	5.47	0.90	0.90	37.1	2158.0
35	845.5	849.4	850.5	0.98	16.9	5.78	1.00	0.95	37.1	2172.0
37	709.1	733.0	757.4	0.96	30.1	5.78	1.04	0.90	43.2	2252.0
38	804.0	829.2	851.3	0.98	17.3	5.68	1.10	0.97	37.8	2177.7
39	804.0	829.2	851.3	0.98	17.3	5.68	1.10	0.97	37.8	2177.7
40	804.0	829.2	851.3	0.98	17.3	5.68	1.10	0.97	37.8	2177.7
41	735.7	762.2	790.0	0.98	17.0	5.75	1.00	0.90	41.3	2220.5
42	845.5	849.4	850.5	0.98	16.9	5.78	1.00	0.95	37.1	2172.0
47	804.0	829.2	851.3	0.98	17.3	5.68	1.10	0.97	37.8	2177.7
50	601.6	616.2	631.4	0.87	90.6	6.91	1.04	0.87	62.7	2864.8
51	714.2	745.1	778.4	0.98	17.8	5.80	1.02	0.90	42.5	2233.0
55	784.5	820.0	853.0	0.98	19.4	5.79	1.21	1.00	38.3	2187.5
56	714.2	745.1	778.4	0.98	17.8	5.80	1.02	0.90	42.5	2233.0
57	601.6	616.2	631.4	0.87	90.6	6.91	1.04	0.87	62.7	2864.8
59	784.5	820.0	853.0	0.98	19.4	5.79	1.21	1.00	38.3	2187.5
61	714.2	745.1	778.4	0.98	17.8	5.80	1.02	0.90	42.5	2233.0
62	686.8	713.9	742.3	0.96	33.0	5.83	1.07	0.90	46.6	2267.7
67	765.0	789.5	812.0	0.98	19.6	5.81	1.21	0.97	39.7	2217.0
68	714.2	745.1	778.4	0.98	17.8	5.80	1.02	0.90	42.5	2233.0
70	714.2	745.1	778.4	0.98	17.8	5.80	1.02	0.90	42.5	2233.0
72	765.0	789.5	812.0	0.98	19.6	5.81	1.21	0.97	39.7	2217.0
73	669.4	677.7	686.3	0.59	476.1	7.59	1.93	0.99	192.3	12267.1
74	662.7	671.4	680.4	0.58	477.4	7.60	1.95	0.99	189.9	11824.2
76	594.0	605.3	617.0	0.51	579.6	7.24	2.13	1.00	162.2	8867.3
77	655.4	664.5	674.3	0.58	475.4	7.57	1.91	0.97	183.4	11391.3
80	655.4	664.5	674.3	0.58	475.4	7.57	1.91	0.97	183.4	11391.3
81	675.4	684.8	694.0	0.62	422.3	8.03	1.80	1.01	204.8	13902.1
82	594.0	605.3	617.0	0.51	579.6	7.24	2.13	1.00	162.2	8867.3

Appendix D. (continued)

Fish no.	Outflow (cfs) min. (OF)	Outflow (cfs) avg. (OF)	Outflow (cfs) max. (OF)	Ratio of outflow to inflow (OF/IF)	Outflow - Inflow (cfs) (OF-IF)	Temp-erature (·C) (T)	Inflow turbid-ity (NTU) (IT)	Outflow turbid-ity (NTU) (OY)	Water particle travel time (s/ft) (WPTT)	Pool content (acre-ft) (C)
83	655.4	664.5	674.3	0.58	475.4	7.57	1.91	0.97	183.4	11391.3
84	661.4	671.7	681.4	0.63	392.1	8.10	1.65	1.03	226.3	15336.5
85	674.3	683.0	692.1	0.60	449.4	7.70	1.91	0.99	198.6	13132.4
86	675.4	684.8	694.0	0.62	422.3	8.03	1.80	1.01	204.8	13902.1
90	672.1	681.4	691.1	0.59	465.6	7.60	1.92	0.99	194.6	12708.9
92	655.4	664.5	674.3	0.58	475.4	7.57	1.91	0.97	183.4	11391.3
93	674.3	683.2	692.0	0.62	418.6	8.09	1.77	1.02	210.5	14269.0
95	662.7	671.4	680.4	0.58	477.4	7.60	1.95	0.99	189.9	11824.2
98	667.6	676.9	686.9	0.59	473.5	7.62	1.90	0.94	188.3	11925.6
100	667.6	676.9	686.9	0.59	473.5	7.62	1.90	0.94	188.3	11925.6
101	667.6	676.9	686.9	0.59	473.5	7.62	1.90	0.94	188.3	11925.6
102	606.0	618.8	632.5	0.50	625.4	7.25	2.20	0.90	168.3	9475.5
103	682.3	691.7	701.6	0.60	463.4	7.63	1.91	0.97	199.1	13214.7
104	682.3	691.7	701.6	0.60	463.4	7.63	1.91	0.97	199.1	13214.7
105	667.6	676.9	686.9	0.59	473.5	7.62	1.90	0.94	188.3	11925.6
106	674.3	683.0	692.3	0.59	476.1	7.65	1.95	0.97	190.6	12345.9
107	667.6	676.9	686.9	0.59	473.5	7.62	1.90	0.94	188.3	11925.6
108	674.3	683.0	692.3	0.59	476.1	7.65	1.95	0.97	190.6	12345.9
109	683.5	693.0	702.3	0.62	417.2	8.09	1.78	0.99	210.8	14383.0
112	681.8	690.7	699.6	0.63	413.6	8.15	1.75	1.00	216.6	14741.7
114	667.6	676.9	686.9	0.59	473.5	7.62	1.90	0.94	188.3	11925.6
117	682.3	691.7	701.6	0.60	463.4	7.63	1.91	0.97	199.1	13214.7
121	692.3	699.2	706.4	0.61	450.3	7.66	1.83	0.98	197.3	13272.8
122	681.2	688.8	697.0	0.61	440.8	7.67	1.78	0.95	192.9	12440.2
124	681.2	688.8	697.0	0.61	440.8	7.67	1.78	0.95	192.9	12440.2
126	681.2	688.8	697.0	0.61	440.8	7.67	1.78	0.95	192.9	12440.2
128	691.6	700.3	708.7	0.64	396.2	8.16	1.71	1.00	212.8	14845.1
129	654.8	665.3	674.3	0.67	329.5	8.53	1.54	1.03	261.9	17096.8
130	693.0	701.3	710.0	0.61	440.4	7.67	1.83	0.98	201.2	13701.0
132	686.9	694.2	701.7	0.61	448.4	7.70	1.85	0.98	195.2	12847.0
134	671.8	681.7	690.8	0.65	368.7	8.21	1.57	1.03	240.8	16223.0
136	691.6	700.3	708.7	0.64	396.2	8.16	1.71	1.00	212.8	14845.1
139	691.6	700.3	708.7	0.64	396.2	8.16	1.71	1.00	212.8	14845.1
140	689.2	697.3	705.2	0.64	393.9	8.21	1.68	1.01	216.6	15195.9
145	502.5	517.3	527.0	0.80	133.0	10.18	0.92	1.05	496.3	22365.5
146	466.3	495.2	511.7	0.78	137.5	10.25	0.99	1.03	522.1	22497.3
147	458.0	479.6	492.0	0.78	137.5	10.39	1.02	1.02	548.8	22638.3
148	502.5	517.3	527.0	0.80	133.0	10.18	0.92	1.05	496.3	22365.5
149	502.5	517.3	527.0	0.80	133.0	10.18	0.92	1.05	496.3	22365.5
150	436.8	447.9	455.6	0.80	114.9	11.03	1.07	1.01	596.6	23246.3
151	447.3	459.7	466.7	0.79	124.0	10.91	1.06	1.01	568.7	23029.0
152	466.3	495.2	511.7	0.78	137.5	10.25	0.99	1.03	522.1	22497.3
153	502.5	517.3	527.0	0.80	133.0	10.18	0.92	1.05	496.3	22365.5
154	466.3	495.2	511.7	0.78	137.5	10.25	0.99	1.03	522.1	22497.3
155	466.3	495.2	511.7	0.78	137.5	10.25	0.99	1.03	522.1	22497.3
157	449.7	464.1	472.3	0.78	130.1	10.74	1.06	1.02	568.7	22907.7

Appendix D. (continued)

Fish no.	Outflow (cfs) min. (OF)	Outflow (cfs) avg. (OF)	Outflow (cfs) max. (OF)	Ratio of outflow to inflow (OF/IF)	Outflow - Inflow (cfs) (OF-IF)	Temp-erature (·C) (T)	Inflow turbid-ity (NTU) (IT)	Outflow turbid-ity (NTU) (OY)	Water particle travel time (s/ft) (WPTT)	Pool content (acre-ft) (C)
158	466.3	495.2	511.7	0.78	137.5	10.25	0.99	1.03	522.1	22497.3
159	466.3	495.2	511.7	0.78	137.5	10.25	0.99	1.03	522.1	22497.3
160	449.7	464.1	472.3	0.78	130.1	10.74	1.06	1.02	568.7	22907.7
161	449.7	464.1	472.3	0.78	130.1	10.74	1.06	1.02	568.7	22907.7
162	453.0	470.3	480.2	0.78	135.3	10.55	1.06	1.02	562.1	22776.4
163	394.7	404.0	411.3	0.79	105.9	10.71	1.04	1.00	659.9	23782.5
164	466.3	495.2	511.7	0.78	137.5	10.25	0.99	1.03	522.1	22497.3
165	449.7	464.1	472.3	0.78	130.1	10.74	1.06	1.02	568.7	22907.7
166	447.3	459.7	466.7	0.79	124.0	10.91	1.06	1.01	568.7	23029.0
167	466.3	495.2	511.7	0.78	137.5	10.25	0.99	1.03	522.1	22497.3
168	449.7	464.1	472.3	0.78	130.1	10.74	1.06	1.02	568.7	22907.7
169	434.8	451.6	461.4	0.78	129.5	10.84	1.11	1.02	581.9	23041.4
170	436.0	464.0	480.3	0.77	138.9	10.42	1.10	1.03	568.7	22771.3
171	435.3	456.3	468.5	0.77	135.7	10.62	1.12	1.02	575.3	22910.8
172	434.8	451.6	461.4	0.78	129.5	10.84	1.11	1.02	581.9	23041.4
173	436.0	464.0	480.3	0.77	138.9	10.42	1.10	1.03	568.7	22771.3
174	435.3	456.3	468.5	0.77	135.7	10.62	1.12	1.02	575.3	22910.8
175	437.5	479.5	504.0	0.77	139.6	10.23	1.08	1.05	548.8	22626.5
176	437.5	479.5	504.0	0.77	139.6	10.23	1.08	1.05	548.8	22626.5
177	435.3	456.3	468.5	0.77	135.7	10.62	1.12	1.02	575.3	22910.8
178	437.5	479.5	504.0	0.77	139.6	10.23	1.08	1.05	548.8	22626.5
179	437.5	479.5	504.0	0.77	139.6	10.23	1.08	1.05	548.8	22626.5
180	435.3	456.3	468.5	0.77	135.7	10.62	1.12	1.02	575.3	22910.8
181	435.3	456.3	468.5	0.77	135.7	10.62	1.12	1.02	575.3	22910.8
182	429.6	443.5	453.3	0.79	117.5	11.18	1.04	1.01	603.4	23268.6
183	429.6	443.5	453.3	0.79	117.5	11.18	1.04	1.01	603.4	23268.6
184	403.6	416.0	426.0	0.81	99.1	11.22	1.08	1.00	630.5	23638.4
185	435.3	456.3	468.5	0.77	135.7	10.62	1.12	1.02	575.3	22910.8
186	381.0	390.6	398.6	0.79	103.5	10.66	1.03	1.00	685.7	23992.6
187	381.0	390.6	398.6	0.79	103.5	10.66	1.03	1.00	685.7	23992.6
188	429.6	443.5	453.3	0.79	117.5	11.18	1.04	1.01	603.4	23268.6
189	385.4	395.2	403.1	0.79	103.9	10.75	1.06	1.00	685.7	23892.8
191	437.5	479.5	504.0	0.77	139.6	10.23	1.08	1.05	548.8	22626.5
192	437.5	479.5	504.0	0.77	139.6	10.23	1.08	1.05	548.8	22626.5
193	413.5	442.0	457.0	0.76	142.0	10.59	1.13	1.00	588.5	22911.0
194	420.0	439.0	449.0	0.76	136.7	10.80	1.15	1.00	602.6	23050.3
195	413.5	442.0	457.0	0.76	142.0	10.59	1.13	1.00	588.5	22911.0
196	413.5	442.0	457.0	0.76	142.0	10.59	1.13	1.00	588.5	22911.0
198	425.2	436.6	442.6	0.78	120.3	11.21	1.11	1.00	610.1	23294.4
200	378.1	386.5	393.5	0.79	101.7	10.80	1.06	0.99	704.5	24000.5
201	420.0	439.0	449.0	0.76	136.7	10.80	1.15	1.00	602.6	23050.3
203	421.0	432.7	441.0	0.79	115.0	11.37	1.04	1.00	616.9	23398.0
204	404.3	416.5	426.7	0.81	97.7	11.37	1.08	1.00	646.0	23672.1
209	421.0	432.7	441.0	0.79	115.0	11.37	1.04	1.00	616.9	23398.0
210	421.0	432.7	441.0	0.79	115.0	11.37	1.04	1.00	616.9	23398.0
211	404.3	416.5	426.7	0.81	97.7	11.37	1.08	1.00	646.0	23672.1